Defense Science Board Report

on

Corrosion Control

October 2004

Office of the Under Secretary of Defense
For Acquisition, Technology, and Logistics
Washington, D.C. 20301-3140

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OFFICE OF THE SECRETARY OF DEFENSE
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DEFENSE SCIENCE
BOARD

13 OCT 2004

MEMORANDUM FOR ACTING UNDER SECRETARY OF DEFENSE
(ACQUISITION, TECHNOLOGY & LOGISTICS)

SUBJECT: Final Report of the Defense Science Board (DSB) Task Force on Corrosion Control

I am pleased to forward the final report of the DSB Task Force on Corrosion Control. This effort was begun in December 2003 at your request to assess on-going corrosion control efforts across the Department of Defense. The attached final report represents the complete work of this Task Force.

The Task Force explicitly outlines five summary recommendations and specific actions to implement those recommendations. The impact of corrosion on systems, equipment, and infrastructure costs the DoD billions of dollars each year. The Task Force estimates 30% of these costs can be avoided through proper investment in prevention and mitigation of corrosion during sustainment, design, and manufacture.

I endorse all of the Task Force's recommendations and encourage you to review the report.

William Schneider, Jr.

William Schneider, Jr.
DSB Chairman

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3140 DEFENSE PENTAGON
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DEFENSE SCIENCE BOARD

12 OCT 2004

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Final Report of the Defense Science Board (DSB) Task Force on Corrosion Control

The DSB Task Force on Corrosion Control has completed its work and a final report is attached. The report emphasizes the importance of leadership commitment and proper incentives for ensuring corrosion is considered early and often in decisions and recommends two major policy shifts. First, to change the basis of acquisition decisions from procurement cost to Life Cycle Cost. Second, to take various steps to provide standards and metrics that will allow data-based decisions. The Task Force outlined five areas of findings and recommendations: (1) leadership commitment and policy, (2) design and manufacturing practices, (3) maintenance practices, (4) funding and management, and (5) scientific basis for prevention/mitigation of corrosion.

The General Accounting Office estimates corrosion costs the DoD from \$10B to \$20B per year. The Task Force found that the DoD does not have any way to track such costs. Properly capturing these metrics is essential for making sound decisions. Investment in corrosion prevention and mitigation practices well before systems require major repair or replacement produces tremendous fleet-wide savings and greatly improves readiness. DoD program managers and other decision-makers need better tools to make such informed decisions.

The Task Force recommendations are delineated in the attached report. We urge the DoD to implement the recommendations at the earliest opportunity.

Larry Lynn
Task Force Co-Chair

RADM Stephen Heilman, USN (Ret)
Task Force Co-Chair

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EXECUTIVE SUMMARY

Weapons system readiness and safety are among the highest priority challenges for the Department of Defense (DoD). As it continues to receive a large number of mission taskings, it is imperative that DoD equipment be maintained at an acceptable level of material condition so that it may be employed safely and effectively when required, often in harsh and physically demanding environments. However, both the material condition and safety of DoD equipment are routinely being undermined by the effects of corrosion. The dollar cost of corrosion to DoD has been estimated by the Government Accountability Office (GAO) to be $10-20 billion per year. Aggressive action is needed at every stage in the life cycle of this equipment — during design, materials selection, construction, operation, and maintenance — to reduce the negative effects of corrosion.

At the request of the Acting Under Secretary of Defense for Acquisition, Technology and Logistics (USD[AT&L]) and the Deputy Under Secretary of Defense for Logistics and Materiel Readiness, the Defense Science Board (DSB) formed a task force to address corrosion control efforts within the DoD. There are two major areas of concern with respect to corrosion for DoD — the Services' weapon systems, including platforms, electronics and munitions, and the supporting infrastructure, including facilities, bases, and ports. Due to the direct impact of weapon system corrosion on combat readiness, the Task Force focused its attention on the former, although both areas are critical to DoD, and much of the subsequent discussion applies to both.

The magnitude of DoD's corrosion problem is uncertain. There have been a number of efforts within the Department to estimate the costs of corrosion; however, for a variety of reasons, these estimates are highly suspect and probably significantly understated. One thing is clear — without aggressive action now, corrosion will almost certainly become a bigger problem, with even higher costs, in the future.

This report divides the findings and recommendations of the Task Force into five areas:

- Leadership commitment and policy
- Design and manufacturing practices
- Maintenance practices
- Funding and management
- Scientific basis for prevention/mitigation of corrosion

LEADERSHIP COMMITMENT AND POLICY

Corrosion prevention has not been a priority within the DoD. As a result, DoD does not have accurate costs of corrosion prevention, mitigation, and remediation, nor does it know what the costs should be. Since corrosion costs are unclear, reform advocates lack compelling arguments for the resources required to reduce corrosion life-cycle cost (LCC). Without a life-cycle perspective and disciplined adherence to comprehensive corrosion reduction plans, significant performance improvement will be impossible.

The Task Force found that most new systems continue to be built with a disparity of outlook between Program Managers who control corrosion prevention decisions and operational commanders who incur the actual corrosion costs. The problem is *not* the Program Manager, it is the system that incentivizes minimum acquisition cost rather than minimum life-cycle cost. In order to make any improvement in this respect, it is essential that there be two policy changes: (1) the collection and use of comprehensive, fact-based information about the extent and cost of corrosion within the Services must be mandated and supported, and (2) Service Acquisition Executives must introduce an effective incentive system in the design and acquisition phase that rewards minimization of LCC .

A key element in any improvement is providing a sound basis for decisions and judgments. The current body of subjective, disjointed, and anecdotal information about weapon system corrosion must be replaced

with credible information based on metrics and data. Quantitative measures of life-cycle corrosion effects are essential to assure responsible investment decisions and effective improvement incentives. These same data are needed to model and predict the utility of alternative corrosion strategies. For the immediate future, absent comprehensive data and good LCC models, prediction of corrosion effects and the corresponding future operation and support (O&S) cost of corrosion will necessarily remain subjective. However, even subjective decisions can be significantly improved by (1) capitalizing on the judgment of independent corrosion control experts, (2) increasing accelerated testing of weapon system prototypes and early production products, with improved correlation between accelerated test results and actual equipment service life, and (3) increasing the use of detailed modeling of high-risk suspect "corrosion prone" areas.

DESIGN AND MANUFACTURING PRACTICES

Decisions made during equipment design establish in-service corrosion properties and consequent life-cycle corrosion costs. If care is taken to focus on corrosion prevention by appropriate choice of materials, fabrication and assembly processes, coatings and coating application, *et cetera*, in-service problems *can* be minimized. It follows that incentives for corrosion cost reduction need to be focused on design and manufacturing.

The most obvious problems in achieving this are (1) that corrosion issues generally require spending funds now for a payoff at some point in the future, perhaps as far out as twenty years, (2) Program Managers of today will be gone in a few years, and (3) estimates of costs and savings have substantial uncertainty.

The current system provides the wrong incentives with insufficient emphasis on longer term savings. The Task Force recommends that an incentive system be put in place that rewards life-cycle corrosion cost avoidance. While the Task Force discussed the attributes of an incentivization plan, including the nature of incentive rewards for Services, Program Managers and contractors, the preparation of a formal plan was

believed to be beyond the scope of the Task Force capabilities. Any useful incentive system must be based on credible predictions of LCC and what it "should cost," and be supported in execution by a disciplined DoD maintenance data collection system — to include maintenance cost. Without a "meter" on planned versus actual corrosion performance, even the best incentive system will surely fail.

Both policy reforms — accurate and objective corrosion data collection and new incentives to reward life-cycle cost reduction efforts — must be implemented; neither by itself will result in improved equipment material condition, safety and readiness, and reduced cost-of-corrosion. It is critical that data be collected and used not only to understand the depth of the problem, but to enable a quantitative corrosion mitigation strategy, which is founded on fact. It is equally critical that Program Managers be incentivized to make the data-driven design trade-off decisions that will result in minimum corrosion and minimum corrosion cost.

MAINTENANCE PRACTICES

The life-cycle cost of weapon system corrosion is almost entirely represented by the cost of maintaining or replacing in-service assets. Although equipment re-design may occasionally be required due to uncontrollable corrosion, the most practical way to generally reduce the *current* cost of corrosion is to do more and/or better preventive maintenance. The Task Force found that industry achieved major savings in corrosion costs by implementing "best practice" maintenance and in-service engineering strategies designed to anticipate, detect, and treat minor corrosion before it progresses to the point where equipment function or structural integrity are placed at risk.

"Best practice" maintenance strategies demand, as a precondition, that the current material condition of supported equipment be well understood and quantified. Achieving a quantitative understanding of the extent of corrosion requires on-site assessments by well-trained, knowledgeable corrosion experts. Some Service maintenance organizations have a robust organic corrosion control capability already in place (e.g., naval aviation

Squadron Maintenance Departments), but most operational units need assistance from outside experts. Capitalizing on such expertise, a small sample assessment for the Marine Corps collected data on 352 equipment items in the 11th Marine Expeditionary Unit. These data were used to make fact-based repair/replace decisions which would have been impossible without the field team's help. The Task Force is persuaded that adopting this approach across DoD would provide a solid basis for improvement. It would quantify the corrosion problem and enable the relative value of alternate corrosion strategies to be objectively evaluated.

FUNDING AND MANAGEMENT

Further confirming the relatively low priority assigned to weapon system corrosion reduction, the Task Force notes that corrosion science and technology (S&T) funding is small, fragmented, and generally comes from unrelated research and development (R&D) accounts such as Small Business Innovative Research (SBIR) and Strategic Environmental Research and Development Program (SERDP). Dollars devoted to corrosion prevention during weapon system RDT&E have historically proved insufficient. There is no specific corrosion remediation budget in Service O&S accounts.

The Task Force concluded that effective Service-level corrosion executive authority, able to advocate on behalf of corrosion-related issues and funding, is currently lacking, and is badly needed. A model that may be appropriate to this challenge is the Service S&T Executive.

SCIENTIFIC BASIS FOR PREVENTION/MITIGATION OF CORROSION

The major S&T objectives with respect to DoD weapon system corrosion should be (1) achieving a science-based understanding of corrosion initiation, propagation, and termination, (2) development of integrated predictive tools for system design and management, and (3) gaining understanding of evolving materials and environmental issues. In each of these areas, important gaps exist.

On the management and funding side of S&T, the Task Force concluded that there was adequate communication across the corrosion S&T community and that duplication of efforts was not a problem. After reviewing ongoing projects, the Task Force found that corrosion S&T funding is largely comprised of either environmentally-driven efforts or Congressional additions; these are beneficial, but totally insufficient to drive down the cost of corrosion. The Task Force also believes that current S&T portfolios are very technological, but appear to be short on research to gain detailed understanding of the underlying corrosion science. Such detailed understanding will be essential for development of the predictive models needed for future cost-benefit judgments. Steady, long-term corrosion S&T funding necessary to achieve a higher probability of successful research application is lacking; the S&T portfolio should contain a mix of long and short term efforts. Additional funding will improve corrosion research at the various DoD laboratories, as well as within the supporting academic community. Increased research needs to be carefully managed to ensure that corrosion science evolves to assist Program Managers with the design of future weapon systems resistant to corrosion, and to assist equipment maintainers to protect and preserve the material condition of fielded systems at the lowest possible life-cycle cost.

RECOMMENDATIONS

The Task Force offers five recommendations which are summarized on the following pages. For each, a series of comments is given related to implementation of the broader recommendation. The FY05 funding needed to implement all of these recommendations is estimated as approximately $50 million.

	Recommendation	Implementation
1	Promulgate and enforce policy emphasizing life-cycle costs over acquisition costs in procurement and provide the incentives and training to assure that corrosion costs are fully considered in design, manufacturing, and maintenance	– Create independent team of corrosion experts to review all programs coming to the Defense Acquisition Board (DAB) and all maintenance plans to provide the expertise necessary to decision makers (<$1M) – Develop incentive structures to assure corrosion/life-cycle cost (LCC) considerations in all designs and manufacturing • Motivate PMs with program flexibility • Motivate contractors with "carrot/stick" fee incentive contracts – Mandate corrosion testing & reporting at all stages of development (see Recommendation 2) – Issue directive to require that all major weapon system Corrosion Prevention Advisory Team (CPAT) members complete a Defense Acquisition University (DAU) developed course on corrosion control – Accelerate the introduction of activity based cost accounting to ensure future visibility into actual LCC including the cost of corrosion

	Recommendation	Implementation
2	Mandate and implement comprehensive and accurate corrosion data reporting systems across DoD, using standard metrics and definitions	– Contract for support in developing standard definitions, metrics, etc to be completed and promulgated within one year ($5M) – Direct Services to conform to these standards and to enable capture of complete and accurate operator, intermediate, and depot level corrosion man-hour, material, and cost data – Use these data to make fact-based decisions regarding corrosion and corrosion cost and to track progress of platform material condition improvement efforts (ROI). (Cost for analysis included in contract above)

	Recommendation	Implementation
3	Fund contract for comprehensive assessment of all DoD weapon system equipment with approximately 30 five-person teams of corrosion experts and use the results to develop and implement a corrosion strategy	– Provide a separate funding line to support annual assessment teams, to provide the means and expertise to manage ongoing maintenance efforts, and to support organizational level training and maintenance ($25M) – Implement well-defined maintenance programs that include continuous corrosion performance improvement and continuing assessment and reporting – Require each Service to contract and execute its part – All results to be reported to common data base for analysis and to support the development of a joint strategy for corrosion maintenance that accommodates the unique factors associated with each Service (and system) – Extend assessment database to capture existing aircraft and ship corrosion data – Direct that Services establish best practices maintenance plans, benchmarking and providing adequate training to all involved personnel at operator, intermediate, and depot levels and across the Services

	Recommendation	Implementation
4	Establish Corrosion Executive for each Service with responsibility for oversight and reporting, full authority over corrosion-specific funding, and a strong voice in corrosion-related funding	– Fund new corrosion mitigation and control initiatives by requiring each Service to: • Establish PE in POM06 of $15M for each service as a starting point • Submit and fund plan, concurrent with PR07, to invest and realize 10% savings (or $300M/yr) in corrosion costs by 2012, well into "self financing" • In absence of credible plan, include $100M for each Service in PR07 and each of the out years

	Recommendation	Implementation
5	Refocus and reinvigorate corrosion S&T portfolio; triple the effective funding in this area (+$20M)	Particular emphasis on: • Development of a materials-corrosion toolset that emphasizes science-based modeling & simulation • Fundamental mechanistic understandings of corrosion phenomena as well as accelerated testing • Substitutes for effective corrosion prevention materials that are being withdrawn due to environmental and safety considerations • Newly developed materials • Non-destructive corrosion sensing/measurement in the field as feedback to prognostic and condition-based maintenance tools

POLICY OVERSIGHT

The Task Force debated alternative organizational locations for corrosion policy oversight within the Office of the Secretary of Defense, and concluded that separate, dedicated policy sponsorship for defense weapons systems and for defense infrastructure was desirable. Within the Under Secretary of Defense for Acquisition Technology & Logistics (USDAT&L), the Installations and Engineering Office is the only logical location for issues dealing with the cost and safety implications of infrastructure corrosion.

The weapons systems responsibility is more complex because there are two major and equally important areas, the "here and now" corrosion challenge represented by weapon system maintenance and repair, and the "corrosion of the future" represented by weapon system design and manufacture. Assigning the responsibility to Defense Systems (DS) is appropriate for the longer term aspects of corrosion cost reduction since that office leads the Defense Acquisition Board (DAB), but DS has little focus on current readiness and operating and support (O&S) costs. On the other hand, Logistics, Materiel, and Readiness (LMR) is completely focused on current readiness and cost, but has little influence in weapon system research and development (R&D) or design.

The Task Force reached no conclusion on the details for policy oversight. One option is to separate the responsibility into the logical three

components that line up with the USD(AT&L) organization and maintain the Principal Deputy Under Secretary of Defense (PDUSD) as OSD focal point. This could be satisfactory if that official can afford the time necessary to give the subject adequate attention through his Office of Corrosion Policy.

CHAPTER 1. INTRODUCTION

Weapons system readiness and safety are among the highest priority challenges for the Department of Defense. As DoD continues to receive a large number of mission taskings, it is imperative that DoD equipment be maintained at an acceptable level of material condition so that it may be employed safely and effectively when required. However, the material condition and readiness of DoD equipment are routinely being undermined by the effects of corrosion. This threat must be addressed. Aggressive action is needed throughout the life cycle of these combat and support systems — during design, construction, operation, and maintenance.

SCOPE

At the request of the Acting Under Secretary of Defense for Acquisition, Technology, and Logistics (USD[AT&L]) and the Deputy Under Secretary of Defense for Logistics and Materiel Readiness , the Defense Science Board (DSB) formed a Task Force to address corrosion control efforts within the Department of Defense (DoD). Specifically, the Task Force was asked to:[1]

- Assess current on-going corrosion control efforts with particular attention to:
  - Duplication of research efforts
  - Application of current and future technology which currently exists in one area to other areas

[1] The complete terms of reference for the Defense Science Board Task Force Report on Corrosion Control is in Appendix I. Appendix II lists the Task Force members. Appendix III provides a list of briefings provided to the Task Force.

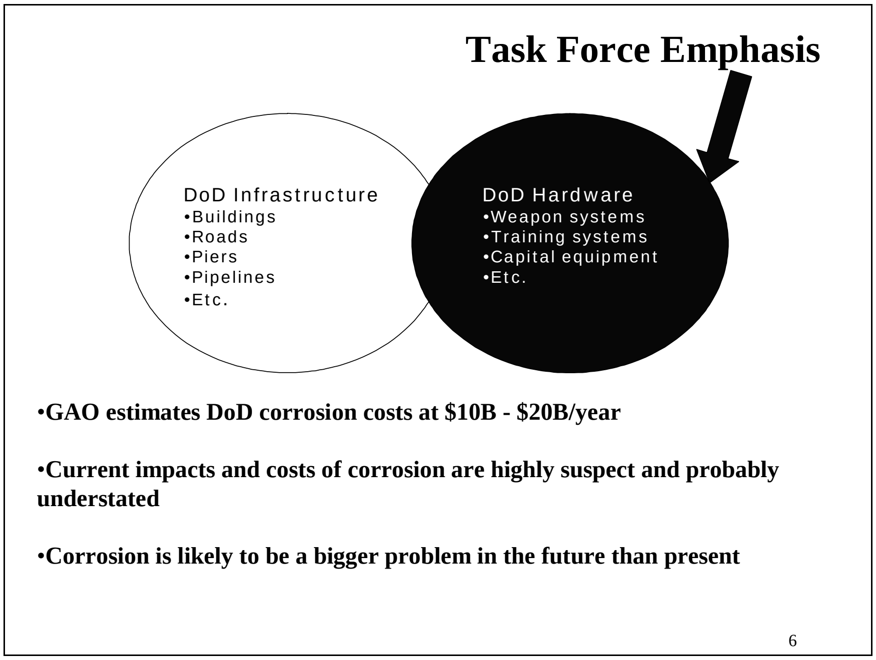
  - Current state of operator and maintenance personnel training
  - Current state of maintenance processes
  - Incorporation of corrosion control and maintainability in current acquisition programs
  - Identification of unique environments important to National Security but with little commercial application
- Determine which areas would provide the most significant advances in combat readiness if adequate resources were applied
- Assess best commercial practices and their applicability

STUDY APPROACH

Corrosion is a problem throughout the Department of Defense. Both the Department's infrastructure and its inventory of hardware suffer the ravages of time and the elements. The Department does not have an accurate estimate of the cost of infrastructure corrosion, nor of equipment corrosion, but the prevailing belief is that the two problems are about equal in dollar terms. There is much more mass on the infrastructure side, but it tends to be cheaper by the pound. Weapon systems are less massive than buildings and runways, but they cost more by the pound to purchase and maintain.

Both sectors need immediate attention, but only the hardware side is *directly* involved in operational readiness and combat capability. Therefore, consistent with the Terms of Reference, the Task Force directed most of its attention to problems associated with DoD weapon system and equipment corrosion as indicated in Figure 1.

Figure 1. Task Force Emphasis



Early in the study, the Task Force discovered that "corrosion" means different things to different people. A number of different definitions were encountered, including:

1. "The chemical or electrochemical reaction between a material, usually a metal, and its environment that produces a deterioration of the material and its properties"[2]
2. "The chemical or electrochemical reaction between a material and its environment that produces a deterioration of the material and its properties"[3]
3. "The deterioration of a material, usually a metal, that results from a reaction with its environment"[4]
4. "The degradation of a material by its environment"[5]

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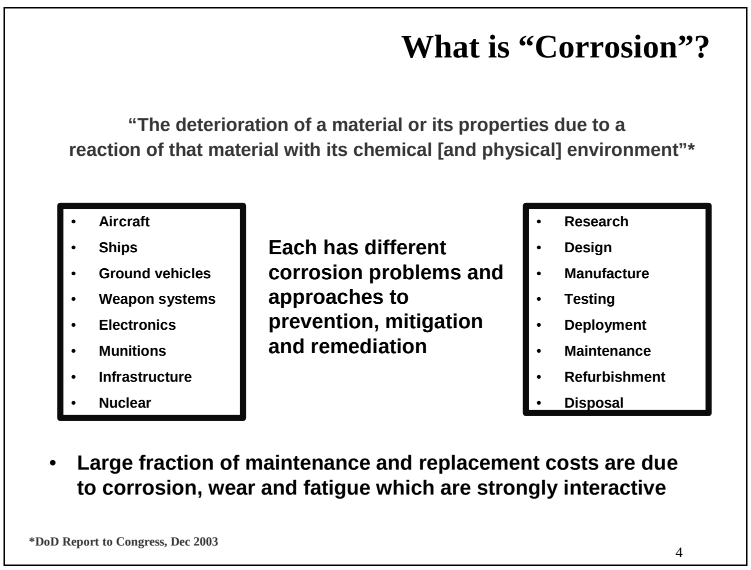
[2] ASTM Book of Standards, G15, in Vol. 03.02, ASTM International.
[3] ASM Handbook, Vol. 13A, p.1014, ASM International.
[4] NACE Glossary of Terms, NACE International.
[5] Ulig's Corrosion Handbook, Second Edition, P.1254, The Electrochemical Society.

5. "The deterioration of a material or its properties due to a reaction of that material with its chemical environment"[6]

Any of these definitions would have sufficed, but for the sake of standardization, the Task Force selected the one used by DoD in its Report to Congress, but added the "physical" environment.

Figure 2. What is Corrosion



A common definition, however, does not necessarily mean common problems and common solutions. The Task Force observed many different materials being used within the different Services, and, of course, different operating environments. The result is a broad range of deterioration characteristics, consequences, and costs across the Department. As well, there is a broad range of opportunities for improvement. See Figure 2.

Most people in the Department of Defense have seen corroded DoD hardware. Most observers, whether laymen or corrosion

[6] Department of Defense, Report to Congress, December, 2003.

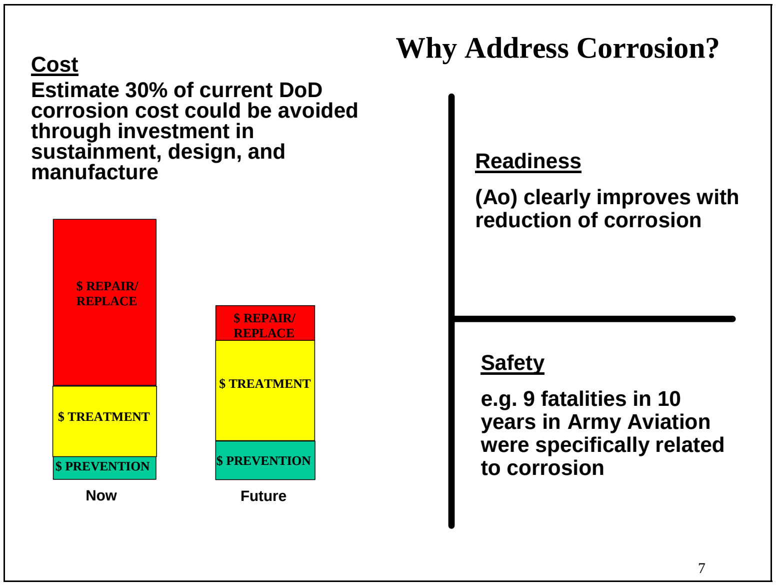
experts, recognize that corroded material is different than uncorroded material. Furthermore, most observers equate corrosion with deterioration.

Physical deterioration is properly associated with reduced safety margins and reduced functionality. Corrosion results in reduced structural integrity and, in extreme cases, loss of life. Assuming the damage is repaired rather than ignored, deterioration due to corrosion is also associated with increased operating and support (O&S) cost.

In addition to the cost of repairing corrosion, equipment out-of-service for corrosion repair is not available for use; operational availability and readiness suffer accordingly. The readiness impact and cost associated with corrosion are generally correlated with the amount of corrosion present. Badly corroded equipment — which may reflect poor design, poor manufacturing processes, and/or poor maintenance — affects cost and readiness far more than lightly corroded equipment. However, untreated corrosion always gets worse. Figure 3 summarizes the impact of corrosion and the gains that can be anticipated from serious corrosion management.

Absent accurate corrosion cost data, it is impossible to quantify potential benefit in real dollars, but there seems to be general consensus, both within the Task Force and among many of the DoD and industry experts who briefed the Task Force, that as much as 30% of current costs could be avoided by preventing more and repairing less. This is not a near-term target because it is heavily dependent on reforms in the DoD weapon system design and acquisition process. Better materials selections, corrosion-resistant designs, higher quality plating and coatings, carefully controlled manufacturing processes, and more disciplined corrosion testing are all required. No reasonable amount of preventive action in the field will keep poorly designed, poorly constructed hardware from suffering corrosion damage. But a well-designed item, given reasonable preventive maintenance, will be much less expensive to operate and support over its full service life.

Figure 3. Why Address Corrosion



One might expect that something so obvious and so deleterious to material condition would have been thoroughly quantified. The Task Force discovered, however, that DoD does not know how much corrosion it is dealing with, nor how much cost is being incurred. This lack of situational awareness impacts many of the specific problems discovered by the Task Force because it deprives problem solvers of the credibility needed to get leadership attention and commitment. A laissez faire culture has emerged within which overwhelming corrosion is taken for granted, and the cost of corrosion is just another cost of doing business.

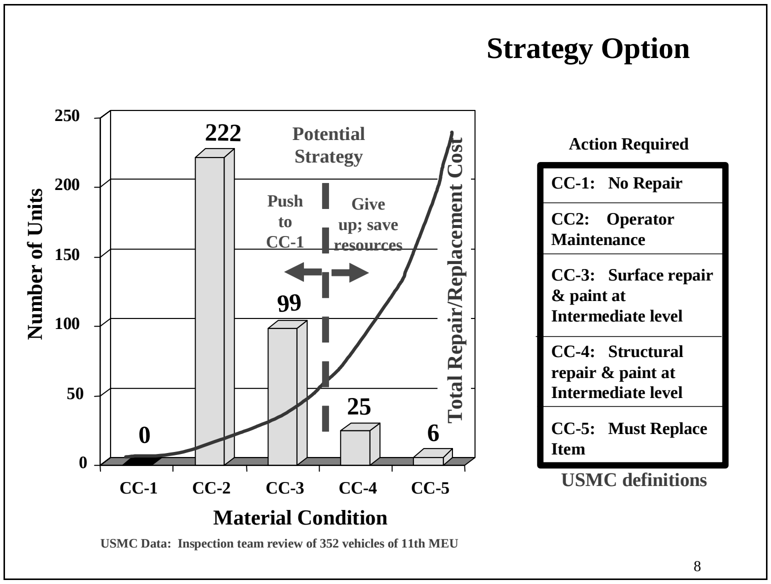
Regardless of what the real cost is, corrosion damage is generally treated as a "must pay" bill because every alternative, at least in the short-term, is unacceptable. Weapons and other equipment purchased by DoD are needed in the field, and they cannot be used if they are unsafe or non-functional.

Equipment availability can be sustained either by preventing failures from occurring or by repairing failures that do occur. In terms of labor and material, it is relatively less expensive to prevent corrosion or treat minor corrosion. It is relatively more expensive to treat major corrosion or repair corrosion damage after it has occurred. And, of course, it can be extremely expensive to replace an asset that is so badly corroded that it is beyond economic repair.

The Task Force asked itself, “Could readiness and safety goals be sustained at required levels with fewer corrosion dollars if DoD managed corrosion differently?” Or, conversely, “Could readiness and safety be improved with the dollars being spent today if DoD managed corrosion differently?”

A small sampling by an expert field team of actual equipment in a Marine Corps Unit with 352 reportable items revealed a high proportion of assets that, although not in “like new” material condition, were in good condition requiring only continued operator attention to prevent further deterioration due to corrosion. The results are shown in Figure 4. This level of organizational maintenance is relatively inexpensive. The on-site evaluations also reveal a small proportion of assets that are corroded to the point of destruction. Replacement of these assets can be extremely expensive.

Figure 4. Sampling and Strategy Option



No piece of equipment reaches the point where it has been destroyed by corrosion, CC-5 on Figure 4 (Beyond Economical Repair), without passing through increasingly unsatisfactory levels of material condition, e.g., CC-4 and CC-3. The total cost of dealing with each level clearly is significantly higher as the item moves to the right on the graph. Figure 5 illustrates a USMC truck assessed at CC-4, "item requires repair at the intermediate level before painting," and provides anecdotal evidence of the current tolerance of the problem.

Figure 5. USMC Truck Ranked CC-4

A management strategy that dealt with all corrosion at the CC-2 and CC-3 levels, routinely restoring these items to CC-1, would almost certainly avoid the most serious CC-4 and CC-5 cases. Without real cost data, which is not readily available, one can only speculate on the cost advantage of doing this. However, it is likely that a great deal of corrosion prevention and treatment could be funded with the dollars currently required to rework or replace the most badly damaged items. A logical approach may well be to focus available resources on restoring CC-2 and CC-3, and immediately replace the 10% in CC-4 and CC-5 condition. Replacement items would not be allowed to degrade below CC-2. Aside from the cost, the readiness and safety implications of such a strategy are obvious.

Whether or not this particular strategy is embraced, information presented to the Task Force suggests that the cost and readiness impact of corrosion can be reduced if the DoD manages the corrosion challenge differently. Significant improvement, however, requires that certain institutional barriers be removed.

The Task Force's examination of DoD's corrosion program revealed numerous opportunities for both short-term (tactical) and long-term (strategic) improvement. As might be expected, many of these opportunities remain unrealized because of the barriers encountered. Five fundamental barriers were identified:

- Leadership commitment and education
- Hardware design and manufacturing processes
- DoD weapon system maintenance practices
- Availability of corrosion control resources
- Gaps in the scientific basis for corrosion control

Not all of these barriers are equal, but improvements will be required in each area if DoD corrosion costs are truly to come down and if DoD weapon system readiness is to improve significantly.

CHAPTER 2. LEADERSHIP COMMITMENT AND POLICY

To put current and on-going DoD corrosion control efforts in context, it is necessary to understand how senior leadership within the Department views corrosion. This view is inevitably shaped by the personal experiences of the decision maker, and colored by the professional culture within which he operates.

Based on the data presented, the Task Force believes that, at the senior level, familiarity with weapon system corrosion is largely anecdotal, and the prevailing corrosion culture is, essentially, laissez faire. The lack of any priority for serious attention reflects the leadership's ignorance of the problem, an ignorance based *not* on incompetence, but rather on a lack of accurate and meaningful data.

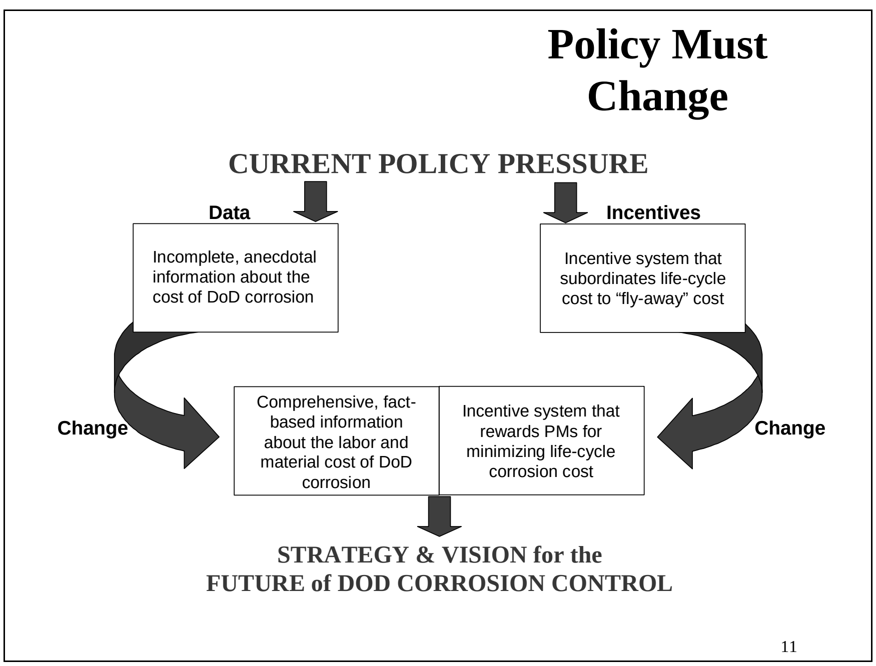
Absent a genuine, fact-based appreciation of the effects that corrosion has on material and equipment, it is not at all surprising that the scarce time and resources available to the leadership are expended elsewhere, such as on better-defined requirements with metrics that support confident investment in improved performance. Standards of performance with respect to DoD life-cycle corrosion cost do not exist. Data systems for documenting, collecting, and compiling the amount and cost of corrosion labor and material consumed annually are highly variable. In general, DoD does not know how big or how expensive its corrosion problem really is. Consequently, it has no strategy for systemic improvement.

There are exceptions of course and the Navy's nuclear power program is a good example. Overall, however, leadership awareness and commitment must be raised to a significantly higher level if comprehensive, sustained improvement of corrosion performance is to be achieved. Responsibility for raising leadership awareness, and motivating commitment rests primarily with the corrosion

community — those who *do* understand the problem and who *do* feel a sense of urgency.

Among the leaders most in need of education are those in the DoD acquisition community. Acquisition community members control the purse strings that fund the decisions which determine 75% or more of weapon system life-cycle corrosion cost. New systems continue to be built with a disparity of outlook between Program Managers (PM) who control corrosion costs and operational commanders who incur the O&S costs. This disparity leads to a mentality of "build it cheap and fix it later." Improved PM awareness, while necessary, is not sufficient to change the culture. Incentives must also be changed so that PMs are routinely *rewarded* for making decisions that will reduce the life-cycle cost (LCC) of corrosion. The problem is not the PM, it is the system that incentivizes minimum acquisition cost rather than LCC.

Figure 6. Policies



In addition, policy guidance is also needed to mandate effective maintenance data collection and reporting systems — specifically including maintenance cost data. Neither of these culture changes will be easy, but only when *both* reforms have taken root can a strategy and a vision for continuous corrosion performance improvement be created and implemented. See Figure 6.

Absent hard data, the basis for making judgment decisions regarding corrosion control alternatives is currently highly subjective. *Decisions need to become objective*. As discussed previously, the data upon which corrosion control decisions are made is currently highly anecdotal. *Data need to become fact-based*.

Additionally, the distinction between “acceptable corrosion cost” and “unacceptable corrosion cost” is nonexistent. Leadership must *define and quantify* the “should cost” in order that standards and metrics may be created and used to track performance improvement. Currently, performance standards are ambiguous and substandard performance is not defined.

The current basis for making decisions about corrosion and corrosion control is dominated by expert opinion, generally not independent of the program. While it would be unfair to categorize these decisions as consistently lacking objectivity, the amount of subjectivity present tends to foster debate that, if left unresolved, compromises consensus. Without consensus, senior DoD leadership will seldom commit significant resources.

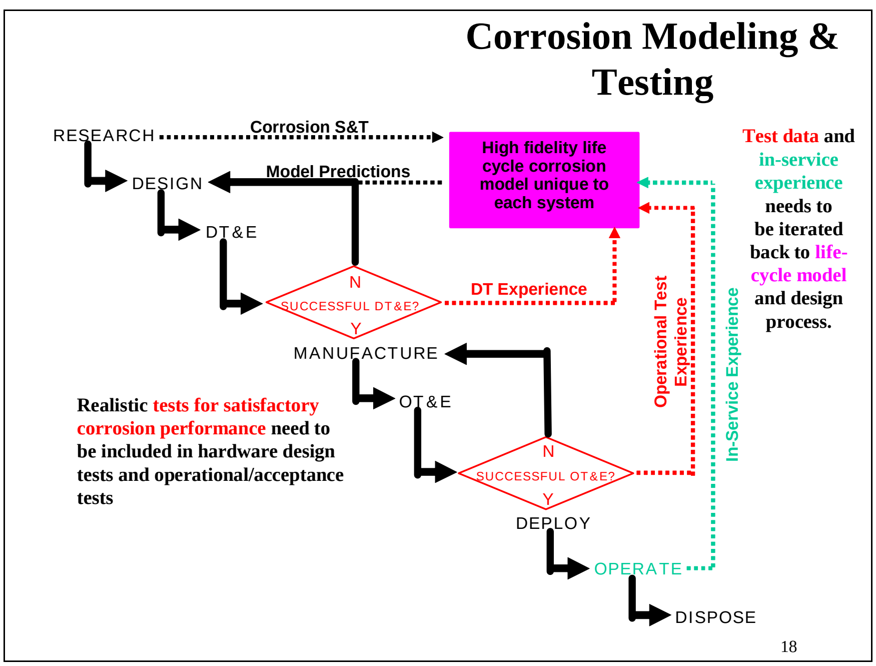
The difference between “educated guesses” and “informed decisions” is hard data. One source of hard data about DoD corrosion is weapon system testing. While there is some ongoing testing, particularly in the S&T arena, this effort needs to be substantially extended into Development Testing/ Operational Testing (DT/OT) to generate the quantity of hard data needed to ensure fielded systems perform as intended. Accelerated Corrosion

Testing should be comprehensive at every stage of development as illustrated in Figure 7.

Weapon system designers and DoD Program Managers routinely test their hardware to evaluate hundreds of performance parameters. Corrosion may or may not be among these parameters, but even when it is included, there is often a question about what to do with unfavorable test results.

Failure to meet corrosion performance standards should be treated no differently than failure to meet any other performance standard —it should require a redesign and re-test. The cost and schedule implications of such an eventuality may be enormous, but they must not be deemed unacceptable. In any case, the cost at later stages of not redesigning and retesting now will almost always be greater.

Figure 7. Corrosion Modeling and Testing



Corrosion testing discipline is one of the first policies that would help incentivize changes in the Program Management culture.

The final challenge requiring heightened leadership awareness and commitment is standards and metrics for corrosion performance. Absent the context provided by corrosion performance standards, even the most accurate corrosion data is meaningless. The Task Force examined a number of areas that had the potential to provide significant advances in combat readiness if adequate resources were applied. As initiatives were discussed and as returns on investment (ROIs) were contemplated, the Task Force frequently found itself asking "how would we know?"

Decision makers need to know what the data are telling them. Knowledge is not created until measured values (data) are compared with required or predicted values (standards). The *quality* of DoD's corrosion program only has relevance in relation to what it "should be," and its cost only has relevance in relation to what it "should cost." The Task Force was unable to find evidence that either of these concepts was well thought out within the Department.

The vision end-state for corrosion decision-making is a reasonably accurate life-cycle corrosion model formed from inputs from independent expert opinion, test and field data reports, and detailed computer modeling of suspect areas selected by the experts for in-depth analysis. While the accuracy of such models will likely not be perfect, it is realistic to believe that *acceptable accuracy* can be achieved, perhaps within the next decade, *if* corrosion data collection systems and in-service information feedback loops are put in place today. Predictions based on the model would be credible. This credibility, taken to the budget table, would generate hardware design strategies and O&S resource levels sufficient to ensure that corrosion performance targets will be met.

The data collection systems and data feedback loops needed to populate and support a corrosion simulation model 10 years from

now are the same collection systems and feedback loops needed *today* to wean DoD away from "educated guesses" and toward "informed decision making." Even without significant modeling, near-term cost and readiness improvements can be expected to derive simply from improved corrosion data collection and management.

When users in the field are capable of presenting credible, fact-based information to the acquisition community, and when Program Managers are incentivized to pay attention to O&S concerns, true culture change can begin.

In a perfect world, *all* of the variables associated with corrosion could be modeled in a high fidelity computer simulation. Reduced levels of periodic testing would be used, not to evaluate hardware designs and manufacturing techniques, but, rather, to validate the model and its predictions. It is unlikely that the degree of detail necessary for modeling to *dominate* the assessment of LCC can ever be achieved or that doing so could be economically practical, so a mix of decision support systems is pragmatically the best goal. For the foreseeable future, prediction of corrosion effects must rely on an integration of three components: judgment of <u>independent</u> experts; accelerated testing of prototypes; and detailed modeling of limited numbers of suspect area, as identified by the experts. All three components are important and should see significantly increased use and capability improvement, where possible. These capabilities need to be directed in support of a well defined, widely understood prediction of the impact(s) of corrosion on weapon system LCC.

FINDINGS

- Corrosion prevention has not been a priority across DoD
- DoD does not have accurate direct and indirect costs of corrosion prevention, mitigation & remediation, nor does it know what the costs should be

- Since corrosion costs are unclear, Service decision-makers lack compelling arguments for resources to reduce life-cycle costs
- At the platform level, decision-makers also lack effective corrosion standards and test methods to assess corrosion performance
- Few decision-makers in a position to reduce life-cycle corrosion costs are incentivized to do so

The issues of leadership commitment and policy are closely related to the other aspects of corrosion prevention and control. Therefore, Task Force recommendations in this area are included in the subsequent sections: design and manufacturing practices, maintenance practices, funding and management, and scientific basis for corrosion prevention and mitigation.

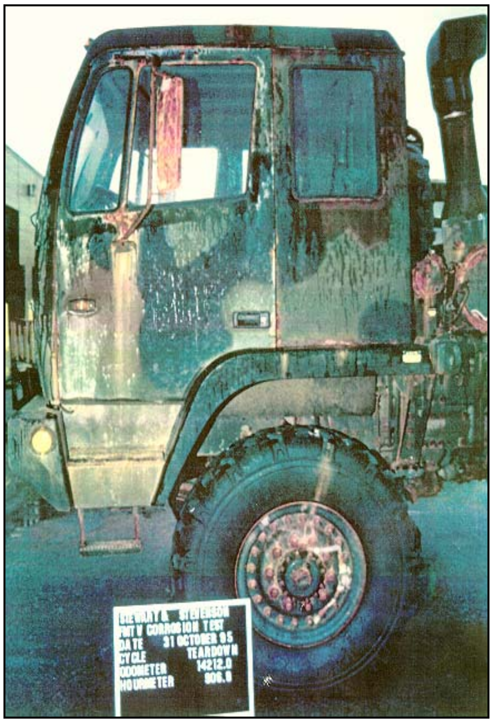
CHAPTER 3. DESIGN AND MANUFACTURING PRACTICES

ANECDOTAL CASE FOR PROBLEMATIC DESIGN & MANUFACTURE

The Family of Medium-Size Tactical Vehicles (FMTV) prototype acquisition provides an instructive case study of the failure of the current system to properly incentivize the design and manufacture of corrosion-resistant weapons. In the early vehicle specification, corrosion engineers recommended that the acceptable level of corrosion in accelerated vehicle testing be limited to "stage 1" corrosion — defined as "corrosion deposit on the surface accompanied by minor etching and pitting; base metal is sound." In the programmatic tradeoff with other competing factors, the Program Manager's vehicle procurement contract was written to allow up to "stage 3" corrosion — defined as "corrosion resulting in erosion of material from the surface; base metal in the corroded areas is unsound and small pinholes may be present." This decision allowed the contractor to use cheaper non-galvanized steel to fabricate the vehicle; galvanized steel would have cost approximately $200 more per vehicle.

When the vehicle was built and tested, it, not surprisingly, showed substantial stage-3 corrosion, as depicted in Figure 8. This poor level of corrosion resistance was not acceptable to the users. The result was a very large expenditure ($10s of millions) to redesign the vehicle to correct the problem, and major delay in the FMTV production deliveries. Since both the PM and contractor initially did what they thought was expected of them, this suggests that the current system by which weapons are designed and manufactured often provides the wrong incentives to key decision-makers.

Figure 8. FMTV After Accelerated Tests



SYSTEM INCENTIVES

Incentives for corrosion prevention during the design, manufacture, and acquisition process must be based upon a reduction of the total life-cycle cost (LCC), instead of the acquisition cost. A consistent and defensible method for calculating the return-on-investment (ROI) for corrosion prevention investments made during the design and manufacturing process must therefore be developed.

There are barriers to success even with a well designed incentive process. Corrosion prevention will almost always require spending

funds now for payoff 5-20 years later. Program Managers of today are usually gone in a few years. Costs and savings can only be estimated, making them vulnerable during inevitable budget drills.

Successful incentives require unambiguous, objective performance standards and credible LCC performance metrics. Since the results of the PM's corrosion control decisions will typically manifest themselves over 20 years or more, the metrics must be based on predictions, which need to be made by corrosion experts. The importance of a well-defined, rigorous and consistent process is obvious, and the availability of a panel of independent corrosion experts is essential.

The nature of LCC reduction incentives will necessarily differ within the targeted population. The commercial sector typically responds to a variation in profits and/or risk in the contract; conventional procurement approaches can provide both positive and negative incentives. Program Managers (PM) are also critical players and are motivated differently; returning some percentage of expected LCC savings to allow the PM the flexibility and resources to fund other aspects of the program is one potential approach. Service Comptrollers also need to be motivated; assuring that program LCC savings are retained within the accounts that generated the savings.

Such an incentive system is essential for motivating improved corrosion performance and genuine reductions in LCC. Credible estimates of ROI demand a large and accurate database for all procured weapon systems. Traceable and quantitative corrosion data for deployed weapons systems is essential. Detailed cost accounting linked to weapon system maintenance is required.

Improved incentives, while necessary, are not, by themselves sufficient to ensure improved corrosion performance. The consequence of the incentivized behavior must be evaluated to confirm that the incentives are having the desired effect. Unless weapon system prototypes are put through some form of rigorous,

accelerated corrosion testing, there is no good way to assess long-term corrosion performance. The complexity of the environment and its effect on the materials is too great to use anything less than empirical field tests. In the distant future, this should not be the case, but the current and foreseeable state of science and technology cannot yet model the vast range of environments, materials, and structural configurations that influence corrosion behavior. Actual testing is the only way to demonstrate that corrosion performance is acceptable.

Demonstration Tests must be programmed into every weapon acquisition program early enough and with enough resources to allow for the identification and correction of corrosion design problems. The Test and Evaluation (T&E) rules and metrics must be clearly spelled out by directive. Accelerated corrosion testing should be included at every stage of development.

MATERIALS SELECTION AND DESIGN

The key to lowering the life-cycle cost of military equipment due to corrosion is to design and manufacture new systems for enhanced corrosion resistance. Weapons systems should be designed with corrosion prevention in mind. Investment in the design phase to prevent corrosion will certainly pay off well in reduction of LCC.

The OSD policy established by a Memorandum of 12 November 2003 on corrosion prevention and control mandated evaluation of corrosion planning during the acquisition process. To meet this requirement Program Managers will require the availability of trained materials engineers to evaluate corrosion reduction measures in new designs. There may not be enough DoD employees with the requisite education and experience to meet this need. For example, in Naval Sea Systems Command (NAVSEA) alone there are currently twenty-six design teams and six new construction ship programs that all require corrosion professionals.

Training in corrosion materials and design measures should be made available for acquisition personnel at the Defense Acquisition University (DAU). This training should be a prerequisite for participation in and leadership of the Corrosion Control Integrated Product Teams.

PERFORMANCE STANDARDS

Performance standards for military material and hardware are almost always tiered, flowing down from the highest and most general description of the required functionality, to the most specific descriptions of the chemical and mechanical properties of individual pieces, parts, connectors, and coatings.

Ideally there is an auditable "if-then" relationship between the corrosion resistant properties of a higher assembly and the corrosion resistant properties of its constituent parts. A properly defined weapon system corrosion performance specification is met by using materials and manufacturing processes that individually meet applicable sub-tier corrosion performance specifications. Said another way, the top-tier standard is not likely to be met if one or more sub-tier standards is not met.

DoD's corrosion program suffers from a lack of performance standards. Top tier corrosion standards seldom exist. When they do exist, they are often "advisory" — subject to being ignored. Sub-tier and process standards, once robust under the umbrella of detailed military specifications (MILSPEC) policy, have also become discretionary guidelines.

Users in the field seldom have difficulty knowing when their weapons are not performing, operationally, the way they were designed to perform. This visibility extends down to the component, sub-component, and even piece-part level (e.g., a microcircuit on a printed circuit card). These same users do not know whether their weapons are corroding the way they were designed to corrode.

Without a standard of performance, there is absolutely no way to identify sub-standard performance. Nor is there a way to determine accountability for safety and readiness problems that may be obviously and directly related to corrosion.

Without an unambiguous standard of corrosion "goodness," and a way to measure and quantify it (metrics), DoD's corrosion program will forever be reactive. *Costs will, by definition, always be out of control because it is impossible to know if they are in control.* How much *should* DoD be spending to control corrosion on the Bradley Fighting Vehicle? On the DDG Class of warships? On the F-15 fighter?

If it does nothing else to manage corrosion differently, DoD leaders need to fill the standards vacuum. Standards and metrics are the most basic tools of management. DoD will never *manage* to solve its corrosion problem without them.

Incentives for corrosion prevention during the design, manufacture, and acquisition process must be based upon a reduction of the total life-cycle cost, instead of the acquisition, or initial procurement, cost. As discussed earlier, this requires that a consistent and defensible method for calculating the return-on-investment (ROI) for corrosion prevention investments made during design and manufacture be developed. Credible estimates of ROI demand a large and accurate database for all procured weapons systems. Traceable and quantitative corrosion data for deployed weapons systems is essential as is detailed cost accounting linked to maintenance.

METRICS AND STANDARDS

Implementation of incentives requires metrics and standards and rigorous, defensible prediction of LCC using a well-defined, widely understood process. Such metrics and standards must also have a clear "cause-and-effect" relationship to mission readiness, personnel safety, and reduced LCC.

A standard method for probabilistic predictions of mission readiness, personnel safety, and LCC from accelerated test data should be established, documented, and uniformly applied across DoD. Accelerated testing should be based on well-established standards to the extent possible. DoD must participate in organizations such as the American Society for Testing and Materials involved in standards preparation.

A rigorous mathematical formulation of ROI for corrosion reduction must be documented and consistently used by all Service Program Managers and equipment operators. This formulation needs to be transparent, easy-to-interpret, and universally accepted by Service Comptrollers.

ADVANCED TECHNOLOGY FOR DESIGN AND MANUFACTURE

"An ounce of prevention is worth a pound of cure." As DoD moves into the twenty-first century, high-performance materials must be found and incorporated during design and manufacturing to eliminate potential corrosion problems before they occur. The computational design of materials, based upon desired performance targets, will soon be within grasp, and should be exploited. Other advanced approaches for the exploration of materials options, including combinatorial synthesis should also be explored. "The synthesis of compounds as ensembles (libraries) and the screening of those libraries for compounds with desirable properties continues to evolve as a potentially speedy route to new compounds and materials… combinatorial chemistry is now firmly established as an important tool in (material) discovery – not so much for synthesizing and screening huge libraries, but for all the combinatorial tools that have been developed. The field does not have to demonstrate its value any more, and expectations for it are now at a realistic level."[7]

[7] Chemistry and Engineering News, October 27th, 2003, pp. 45-45.

PREDICTIVE CAPABILITY NEEDED FOR DESIGN

As discussed in the section on the needed scientific research, a well-coordinated research and development program could enable the development of an integrated corrosion model for predicting equipment failure and mission readiness at the component or subsystem level. A comprehensive corrosion performance-assessment family of codes will include a deterministic sub-model for time evolution of surface environments, and for predicting the initiation, propagation, and cessation (stifling, arrest) of each mode of corrosion-related failure (pits, crevices, cracks). Formal and controlled model abstraction is needed to facilitate probabilistic risk assessment. The uncertainty and variability of all parameters and inputs are also needed. The application of neural networks, expert systems, and the development of computer aided design or computer aided manufacture (CAD/CAM) systems to guide the creation of corrosion resistant designs needs to be explored.

Carefully designed experiments should be used for calibration and validation of corrosion models. The associated experimental program will have to address: aging and phase stability; the evolution of deliquescence brines, biofilms, and other surface environments; general and localized corrosion in those environments; microbial-influenced corrosion; stress-corrosion and hydrogen-induced cracking; corrosion fatigue; and the stress distributions that drive environmental fracture.

INTEGRATION OF HIGH PERFORMANCE MATERIALS & SENSORS

Many advanced materials solutions have already attained a reasonably high degree of maturity, and could be applied to some of the corrosion and wear problems that are being encountered within the DoD. While incomplete, a list of such materials and fabrication innovations that could be considered during the design and procurement of new weapons systems include:

- Electro-coatings and wear-resistant thermal sprays

- Substrates designed for coating application
- Smart materials with sensing and self-healing capabilities
- Better joining technology
- Welding processes with minimal heat affected zones, such as reduced-pressure electron-beam welding
- Stress mitigation with advanced processes such as laser peening

New weapons systems should be designed and built with integrated sensors to provide the warfighter and other decision makers early warning of potentially catastrophic failures in weapons systems that are due to corrosion and other materials degradation phenomena. Such integrated diagnostics, if reliable and robust, will build confidence on the battlefield. A variety of methodologies for the potential integration of sensor technology into new weapons systems have been identified, such as:

- Smart coating technology that also serves as indicator of underlying corrosion
- Advanced non-destructive evaluation methods, such as laser-based methods for stand-off non-contact detection of corrosion and environmental fracture

Caution must be exercised in adopting new materials for incorporation into weapons designs—specifically in regards to "green" (environmentally friendly) coating technology. All chromate replacements should be subjected to toxicology studies comparable to those used for chromate coatings. Many of the chromate replacements also involve oxidizing species (such as cerium) that may pose a long-term cancer risk. Substantially more emphasis should be placed on non-cerium chromate conversion coatings. All funded research should include tests aimed at the early identification of barriers to transition.

FINDINGS

After reviewing a large number of presentations from the various Services, as well as presentations from industry, a number of findings pertaining to design and manufacture of weapons systems with enhanced corrosion resistance emerged.

- The design phase largely establishes future corrosion and life-cycle costs
  - Material, coatings selection and structural aspects are critical
  - Corrosion specialists must participate
  - The most advanced technologies from commercial world must be considered
- Predictive corrosion models adequate for guiding the design of weapons systems do not exist
- Maintenance cost accounting systems adequate for estimating return on investment (ROI) do not exist
- Acquisition and design personnel are not empowered with the training necessary to minimize the impact of corrosion on life-cycle costs
- Independent expert panels are not used to review the selection of corrosion resistant materials, coatings, etc. used in new systems
- Existing DoD corrosion standards and metrics vary widely in quality and are often “advisory” in nature

RECOMMENDATIONS

	Recommendation	Implementation
1	Promulgate and enforce policy emphasizing life-cycle costs over acquisition costs in procurement and provide the incentives and training to assure that corrosion costs are fully considered in design, manufacturing, and maintenance	– Create independent team of corrosion experts to review all programs coming to the Defense Acquisition Board (DAB) and all maintenance plans to provide the expertise necessary to decision makers (<$1M) – Develop incentive structures to assure corrosion/life-cycle cost considerations in all designs and manufacturing • Motivate PMs with program flexibility • Motivate contractors with “carrot/stick” fee incentive contracts – Mandate corrosion testing & reporting at all stages of development (see Recommendation 2) – Issue directive to require that all major weapon system Corrosion Prevention Assessment Team (CPAT) members complete a Defense Acquisition University (DAU) developed course on corrosion control – Accelerate the introduction of activity based cost accounting to ensure future visibility into actual life-cycle cost and cost of corrosion

Recommendation #1 is to promulgate and enforce a policy emphasizing LCC over acquisition costs in weapon system procurement and provide the incentives and training to assure that corrosion costs are fully considered in design, manufacturing, and maintenance. Five elements of implementation are listed with a total near-term investment cost on the order of $1 million, primarily to assemble a standing team of corrosion experts to advise decision makers.

	Recommendation	Implementation
2	Mandate and implement comprehensive and accurate corrosion data reporting systems across DoD, using standard metrics and definitions	– Contract for support in developing standard definitions, metrics, etc. to be completed and promulgated within one year ($5M) – Direct Services to conform to these standards and to enable capture of complete and accurate operator, intermediate, and depot level corrosion man-hour, material, and cost data – Use these data to make fact-based decisions regarding corrosion and corrosion cost and to track progress of platform material condition improvement efforts (return on investment). (Cost for analysis included in contract above)

Recommendation #2 is to mandate and implement comprehensive and accurate corrosion data reporting systems across DoD, using standard metrics and definitions that will be developed. In this case, three specific implementation actions are shown with a cost estimated at about $5 million, largely for contract support in the development of standards and metrics.

CHAPTER 4. MAINTENANCE PRACTICES

DOD WEAPON SYSTEM MAINTENANCE PRACTICES

The services pay for corrosion repairs mostly out of operating funds as a "cost of doing business." When a corrosion condition results in material degradation, the owner must pay to have it fixed. The longer he waits, the worse the problem. Separating the cost of corrosion from other maintenance costs is difficult if not impossible with existing Service Maintenance Data Collection Systems (MDCS), as corrosion is almost always a factor in the overall material condition of any weapons system. The cost of corrosion is often buried within the current cost of maintaining or replacing existing assets.

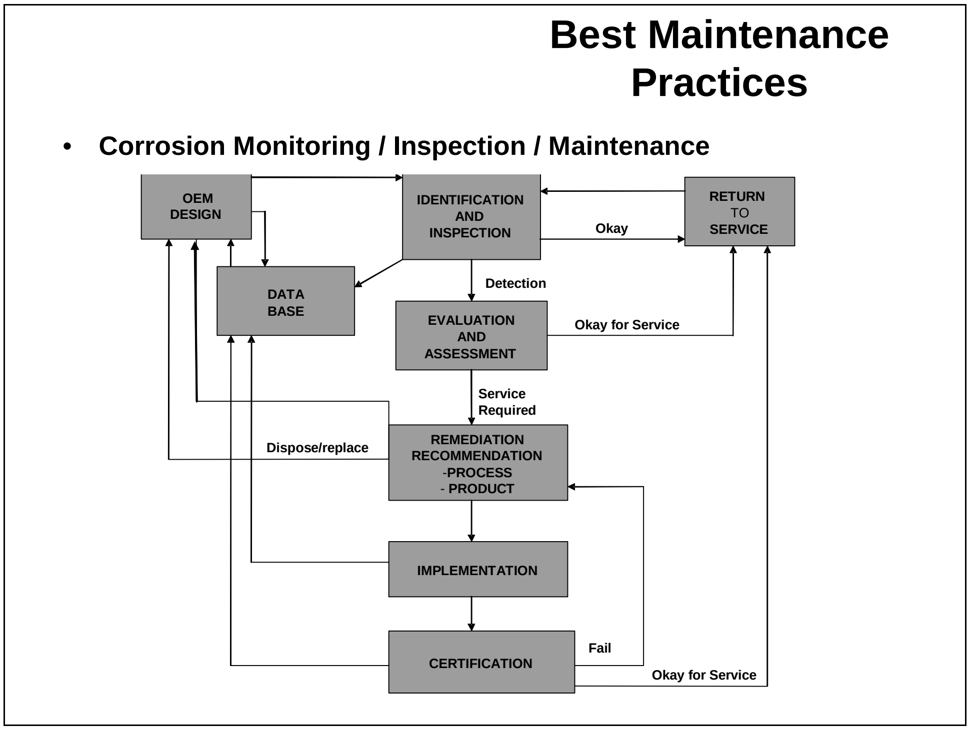
Lacking an overarching DoD strategy for addressing the problem of weapon system corrosion, the Task Force found that most current improvement initiatives are the result of isolated instances of the application of a new technology or due to a transient military leader who makes corrosion reduction a personal priority. These single-point solutions, although commendable, will not solve the systemic problem.

In order to address the global challenge of current, in-service corrosion, there must be a clear understanding of the extent of the corrosion problem and a link between the corrosion problems in the field and the alternative maintenance strategies available to address them. The Task Force was briefed on several private sector strategies for addressing equipment corrosion in their respective industries (heavy equipment, airline, etc.). In benchmarking commercial equipment operators, the Task Force found a common thread often summarized as "Best Practice Maintenance." This approach, which generally translates into "least cost (life-cycle cost!) maintenance," has direct applicability to the DoD. Corrosion preventive methods and practices, and continued process improvements that make up a

"best practice maintenance" program are always "top-down" driven with a real commitment by those at the highest level of authority.

"Best Practice Maintenance" is also data-driven maintenance. Once the major corrosion cost drivers are identified and the cause and extent of corrosion are understood for a specific system or component, a strategy and program to fix the problem is devised. Corrosion monitoring and inspection is closely tied to maintenance practices. Maintenance is most effective when problems are identified at the earliest possible date before damage becomes severe. Therefore, a comprehensive inspection and evaluation program is performed to identify a problem and assess/classify its severity to insure effective maintenance practices are implemented early. Proper training of personnel at the different levels of maintenance is critical to insure the effectiveness of a "best practice maintenance" program. When properly implemented, lessons learned from the corrosion program will drive future design, acquisition, and performance specifications. Therefore, the implementation of a "best practice maintenance" program must include a means of returning equipment corrosion performance data back to the cognizant engineering and design agency. Only in this manner, can the full benefit and cost savings associated from a "best practice maintenance" program be realized. Figure 9 shows schematically the interaction of the components of a "best practice maintenance" program.

Figure 9. Best Maintenance Practices



PERIODIC INDEPENDENT ASSESSMENT STRATEGY

Many of the principles of commercial "Best Practice Maintenance" are found in DoD's Condition Based Maintenance. Condition based maintenance is an efficient means of establishing the need for periodic maintenance during the life of a component. This requires monitoring and inspecting the component at regular intervals, or better yet, some means of continuous monitoring. Several methods of monitoring are under development through field trials and R&D. Regular routine inspections for the purpose of condition based maintenance requires the training of personnel at the user level. Both of these will require time to implement and probably will result in very basic inspections without the assessment/evaluation of severity of the corrosion problem, which requires a more significant level of training than the identification of the problem. In addition, it is very difficult to establish program needs and requirements when there is

presently no means of knowing the extent of the problem throughout the Services.

While some segments of the DoD already employ relatively mature and robust corrosion mitigation strategies (e.g, naval nuclear reactors, naval aviation), the majority of DoD weapons and equipment are operated and maintained with only relatively casual regard for corrosion reduction. Consequently, much of the inventory is corroded. Unfortunately, as discussed previously, no one knows how much or how badly. There is a significant need to assess corrosion for all DoD assets (weapon systems and facilities). This comprehensive assessment should have the following purposes:

1. To establish the corrosion condition of DoD assets at the beginning of DoD's implementation of a Services-wide corrosion reduction program. Subsequent assessments will permit the effectiveness of DoD's corrosion strategy to be evaluated.

2. The assessment will characterize the types of problems identified and permit comprehensive maintenance strategies and solutions to be established.

3. The initial assessment will lead to the establishment of best practice procedures for data collection, for assessing large numbers of assets, and for the establishment of measures and metrics for assessing corrosion for a particular system or facility component.

4. The initial assessment will serve to populate the data base on the corrosion condition of DoD assets.

5. The assessment teams can simultaneously train local teams for the purpose of routine condition assessments and

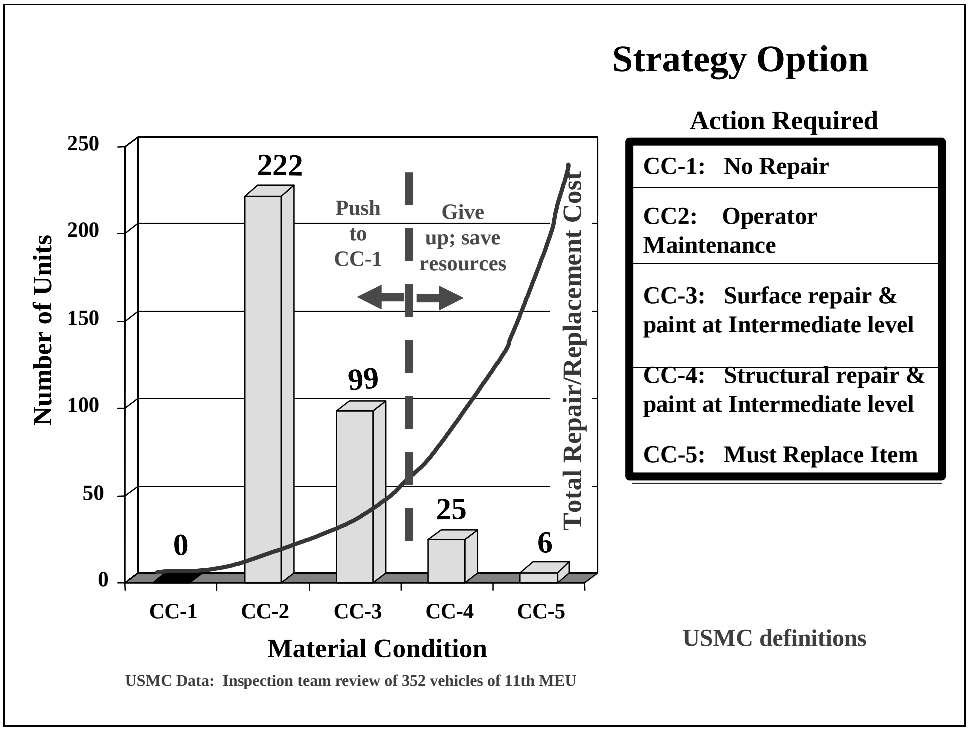
identification of problems to be used in a condition based maintenance program.

The best method to accomplish the above goals is to send out small teams of independent corrosion experts to conduct an assessment of DoD assets. This should start with an assessment team visiting one or a few sample sites to develop a repeatable process for all.

An example of a model program is the USMC corrosion assessment effort at the 11th MEU (see Figure 10). However, while the USMC effort ranks maintenance requirements, it does not evaluate and characterize the extent and type of corrosion damage, which would also need to be included in the field team assessments to accomplish the described goals.

This assessment would provide a sound basis for establishing DoD-wide corrosion reduction strategies. The results of the surveys would also provide a baseline for a prioritized list of corrosion problems for use in building remediation budgets. The cost of corrosion repairs would be identified and rolled up for use in assessment of new weapon system designs.

Figure 10. Periodic Assessment



BENCHMARKING

An initial step in establishing a "best practice maintenance" program requires knowledge about other programs with similar problems. Benchmarking other programs can be conducted simultaneously with the initial corrosion assessments. For ground vehicles and equipment, a detailed review of the USMC model for characterizing maintenance and how and where the maintenance will be performed would be a reasonable starting point. Benchmarking within the DoD is important, but benchmarking industry practices is also critical. Although it is clear that there are significant differences in drivers between a for-profit-industry-leader (Delta, UPS, etc.) and DoD, reviewing the maintenance practices and incorporating critical aspects of an overall best practice maintenance program is important. An area to look at for facilities including pipelines, roads, bridges,

and substructures is Department of Transportation (DoT). For instance, the Office of Pipeline Safety of the DoT provides regulations for the operation and integrity management for buried pipelines.

In our look at industry practices, it seems clear that the more successful efforts repair corrosion effects as soon as detected (i.e. CC-1 or CC-2 in the model illustrated in Figure 4) and thus prevent more severe impacts. This is a likely starting point in defining DoD strategies and policies.

It would be very inefficient for each Service to perform independent benchmarking studies. These studies should be coordinated at a high level. Each best-practice-maintenance-program for a system or component should have the same basic framework and reflect the overall philosophy established and promoted by the DoD. This will require a strong, centralized effort.

TRAINING

Maintenance training in general, and corrosion control training specifically, is highly variable within and among the Services. Additionally, the various warfare communities have different maintenance cultures. At a high level, there are two basic approaches to weapon system maintenance: maintenance performed by those who operate the equipment, and maintenance performed by dedicated, professional maintainers (who are not operators). Typical of the former are Army and Marine Corps ground combat units and Navy ships. Typical of the latter are aviation Squadrons (all Services). Additionally, most warfare communities are supported by Intermediate Maintenance Activities (IMAs) staffed by maintenance professionals (who are not operators). All Services also operate large depot industrial facilities also populated by maintenance professionals —usually civilian — who are not operators. Within this large and diverse operator/maintainer population are many with significant corrosion control training and many more with none. Because of the hostile operating environment and the safety

implications of a corrosion-induced structural failure, all naval aviation Squadrons, for example, have very capable Corrosion Control Workcenters staffed by well-trained professionals. Naval aviation IMAs and naval aircraft depots are likewise staffed with corrosion experts. Professional maintainers, in all Services and at all maintenance levels, expect to be tasked to fix things —this is their chosen career field. On the other hand, the weapon system operators, who generally do not have journeyman level maintenance skills, do not expect to be required to fix things. They expect their equipment to work when they need it and to be provided what they need to do their war-fighting job. They generally do not enlist to paint their ships and vehicles.

As might be expected, much of DoD's current "corrosion crisis" seems to be centered in the warfare communities which do not have routine access to trained maintenance professionals. This does not to imply that the Air Force, Army aviation, or Naval aviation are without significant corrosion problems, but it does suggest that, from the standpoint of corrosion control training, aviation seems to have a leg up.

Corrosion is a complex process that can manifest itself in many forms, some of which are easy to recognize (large amounts of corrosion products on bare or poorly coated surfaces, deep pitting that may go through a wall, and severe blistering of a coating due to corrosion beneath the coating); while other forms may be difficult to detect and assess (crevice corrosion, corrosion at joints, stress corrosion cracking, corrosion fatigue, small pits, or even deep pits that are very small but penetrate deep into the metal). It is not reasonable to expect all military personnel to be corrosion experts. Therefore, training must match both the individual's expertise and the job function he/she is expected to perform. Training programs must be developed and taught at the different levels of maintenance and responsibility (operator, intermediate, depot, and program manager office).

The corrosion training that the operator gets should therefore only be to recognize what causes corrosion and the consequences of not taking reasonable preventive measures. Training is primarily on-the-job training.

At the intermediate and depot level, corrosion training and expertise is important. This is particularly true in the aviation communities, where aircraft maintainers are trained to correct corrosion problems on aircraft as a vital part of safety. The requirements of this training, at the different levels, are outlined in Figure 11.

At the Program Manager level, basic decisions are made with respect to the implementation of corrosion control strategies. It is important that at this level, benefits of different preventive methods be appreciated and that savings as identified by life-cycle costing be understood.

Figure 11. Training Requirements

Training Requirements

- Operator Level (Soldier, Sailor, Marine)
  - Knowledge/awareness of importance of corrosion
  - Primarily On the Job (OJT)
- Intermediate Level (military and civilian)
  - Knowledge of corrosion prevention measures
  - Technical training for corrosion prevention
  - Basic corrosion maintenance assessment methodologies
- Depot Level (Private and Public)
  - Knowledge of long term corrosion measures
  - Inspector training for coating application and QA
  - Detail corrosion assessment methodologies
- Program Manager Office Level
  - LCC for maintenance/repair/replace decisions
  - Detailed implementation of corrosion control methods

FINDINGS

- Extent of maintenance needs and current state of corrosion is not well characterized for most non-aviation assets
- Quantitative understanding of the corrosion problem requires comprehensive, on-site assessments
- It has been shown in industry that major savings in corrosion cost can be achieved through instituting "best practice" engineering and maintenance strategies
- Appreciation and implementation of corrosion control practices varies significantly throughout the services
- Systematic corrosion control training and awareness among operator-maintainers is lacking
- Consistent and comprehensive corrosion control and maintenance strategies throughout all Services and for all systems including infrastructure does not exist

RECOMMENDATIONS

	Recommendation	Implementation
3	Fund contract for comprehensive assessment of all DoD weapon system equipment with approximately 30 five-person teams of corrosion experts and use the results to develop and implement a comprehensive corrosion maintenance strategy	– Provide a separate funding line to support annual assessment teams, to provide the means and expertise to manage ongoing maintenance efforts and to support organizational level training and maintenance ($25M) – Implement well-defined maintenance programs that includes continuous corrosion performance improvement and continuing assessment and reporting – Require each Service to contract and execute its part – Report all results to common data base for analysis and to support the development of a joint strategy for corrosion maintenance that accommodates the unique factors associated with each Service (and system) – Extend assessment database to capture existing aircraft, ship, and facility corrosion data – Direct that Services establish best practices maintenance plans, benchmarking and providing adequate training to all involved personnel at operator, intermediate, and depot levels

Recommendation #3 is to fund a contract for comprehensive assessment of all DoD weapon system equipment with approximately 30 five-person teams of corrosion experts and use the results to develop and implement a comprehensive corrosion maintenance strategy. This set of assessment teams is estimated to cost approximately $25 million per year and should be continued indefinitely. In addition to the initial DoD-wide assessment including both weapon systems and infrastructure, which should be completed in about 2 years, these groups can and should help in maintenance in high-corrosion areas as well as periodically revisiting all DoD systems and facilities.

CHAPTER 5. FUNDING AND MANAGEMENT

The importance of corrosion in terms of cost and operational readiness has been well established. How to deal with it has not. Corrosion prevention and control affects the entire life-cycle of a weapons system. Responsibility for corrosion therefore crosses over existing organizational boundaries of S&T, acquisition, and operation. Centralized funding and management is needed to cross these boundaries, integrate corrosion control efforts, assemble and distribute corrosion data, set overall policy, and reduce the cost of corrosion.

FINDINGS

- Effective corrosion executive authority to advocate corrosion-related issues/funding is lacking at the Service level
- Corrosion S&T funding is small and fragmented
  - Funded out of unrelated R&D accounts within DoD (SBIR, SERDP, etc.)
- Dollars devoted to corrosion prevention during weapon system acquisition have historically proved insufficient
- O&M corrosion remediation budget does not exist
- The Task Force assumed an annual DoD weapon system/hardware corrosion cost of $10B/yr, a potential reduction of 15% (~$1.5B) by 2015 and an average ROI of 10:1 to estimate required funding. To the extent these estimates are valid, an annual investment of $58M/yr per Service is required

When a need for improved corrosion control coordination between Services was recognized at many levels, including Congress, a DoD office of corrosion policy and oversight was established. This office provided the focus to make significant progress in addressing corrosion control issues. Although this is recognized as a positive step by the Task Force and a continued requirement for establishment of centralized DoD corrosion control policy, there is an additional need for a direct Service-led approach.

Corrosion funding decisions are often made at a level that does not produce optimum results.

- Funding for corrosion S&T competes with other S&T areas with no priority given to the corrosion needs of each Service
- During the design phase of new weapon systems, selection of materials and designs are made based on short term considerations. This often results in increased maintenance after deployment and increased life-cycle costs
- Deployed weapon systems are maintained from operating accounts without provision for corrosion prevention expenditures

RECOMMENDATIONS

	Recommendation	Implementation
4	Establish Corrosion Executive for each Service with responsibility for oversight and reporting, full authority over corrosion-specific funding, and a strong voice in corrosion-related funding	– Fund new corrosion mitigation and control initiatives by requiring each Service to: • Establish PE in POM06 of $15M for each service as a starting point • Submit and fund plan, concurrent with PR07, to invest and realize 10% savings (or $300M/yr) in corrosion costs by 2012, well into “self financing” • In absence of credible plan, include $100M for each Service in PR07 and each of the out years

Recommendation #4 is to establish a Corrosion Executive for each Service with responsibility for oversight and reporting, full authority over corrosion-specific funding, and a strong voice in corrosion-related funding

It is recommended that a memorandum be issued by USD(ATL) to each of the military services to establish a Corrosion Executive (possibly modeled after the existing S&T Executive). This senior leadership position would provide a focal point for the DoD corrosion executive in the coordination of inter-service initiatives and as an advocate for corrosion prevention funding requests and allocations.

In order to provide the same focal point for corrosion issues as was found necessary in DoD, each Service needs to establish a Corrosion Executive to enforce Service corrosion policy. As a starting point, each Service needs to set aside resources for the Corrosion Executive to function. Assuming an annual DoD corrosion cost of $10B and a conservative potential reduction of 15%, or about $1.5B with a 10 to 1 ROI, an investment of $60M per Service is reasonable. In addition, a separate funding line is needed to support the continuation of assessment team visits. Based on the findings of the assessment teams, well-defined corrosion maintenance programs

(such as Marine Corps Corrosion Service Teams and Navy Paint Teams) need to be implemented to ensure continuous performance improvement.

It is recommended that DoD acquisition regulations be changed to require that all personnel assigned to Corrosion Control Integrated Product Teams (CCIPT) be graduates of a comprehensive acquisition related corrosion training course.

It is recommended that, to the extent possible, field corrosion prevention and control maintenance efforts be done by contracted civilian teams of highly trained professionals to implement corrosion prevention measures on vehicles and ships using the best available technologies. It is further recommended that the specific corrosion repairs made by the teams be based on a periodic detailed corrosion survey.

CHAPTER 6. SCIENTIFIC BASIS FOR PREVENTION AND MITIGATION OF CORROSION

Corrosion S&T can favorably impact all aspects of the design, acquisition, deployment, and sustainment of DoD weapons and equipment to help achieve the goal of decreased corrosion control costs. The Task Force is optimistic that an invigorated S&T investment could enable accelerated development of new cost saving strategies for corrosion control. Without such an effort, it is believed that corrosion control costs will rise in the future due to several challenges that cannot be solved with off-the-shelf corrosion control technology.

The DoD program in Science and Technology for corrosion should be focused on establishing an improved scientific basis for prevention and mitigation of corrosion in DoD systems. Toward that end, the major S&T objectives should be:

(1) Achieving science-based understanding of corrosion initiation, propagation and termination, including the basic science of accelerated corrosion testing so that there is a sound basis for use of acceleration factors and confidence in the applicability of accelerated tests.

(2) Development of integrated predictive tools for equipment design and support, and improved sensing of the evolution of the deterioration process to provide input data for life prediction models.

(3) Gaining understanding of the corrosion properties of evolving materials and the effects of emerging environmental issues on DoD corrosion control efforts.

These are discussed in the following sections.

NEED FOR SCIENCE-BASED UNDERSTANDING

Much of the data that are available concerning corrosion are empirical and, therefore, generally unsuitable for extrapolation to different materials or environmental circumstances. The quantity of these data is impressive, but the utility questionable.

A classic example is the study of galvanic corrosion. When bimetallic couples are exposed, the information obtained applies directly to those two materials in the environment tested. It cannot be used beyond that situation. Relevant empirical bimetal couple data were not available when a new bimetal couple was built into artillery equipment and galvanic corrosion became a problem. An alternative approach would be to construct a library of electrochemical polarization data on a large variety of alloys in pertinent environments and then model galvanic current and potential distributions for any geometry using mixed potential theory and finite element analysis. The result of such a fundamental S&T effort would lead to a portable, long lasting tool and database that could predict galvanic corrosion behavior for a much broader range of alloy/environment combinations. More fundamental research in corrosion metallurgy and defect sensing is generally of greater intrinsic value if it is conducted at the appropriate investigative-science-level. The most useful research would engage the crossroads of corrosion, electrochemistry, metallurgy, and surface science. If we fail to move in this direction, there is Task Force consensus that corrosion costs are likely to rise in the future due to limitations in existing fundamental knowledge and the lack of materials/corrosion tool sets.

Another example was a Navy laboratory test of dozens of different coatings candidates for a new marine amphibious vehicle to be constructed of high strength aluminum alloys. Since each coating was of different thickness, inhibitor content, and adhesion capability,

it would be difficult to ascertain which of these factors was responsible for good coating performance. These tests and evaluations could arguably produce very practical results that directly determine the best coating for the exact system under study, but the results would be empirical and create very little long lasting fundamental knowledge that extended beyond the design at hand.

The shortcomings pointed out here are exacerbated by other pressing issues such as increased use of legacy weapons and equipment beyond design lifetimes as well as restricted usage of proven corrosion control strategies due to worker safety and environmental compliance requirements. For instance, the Occupation Safety and Health Administration (OSHA) is currently under court order to propose a change to the personal exposure limit for hexavalent chromium no later than October 2004. The new limit for hexavalent Cr could be up to 100 times lower than the current limit. In addition to OSHA regulations, the EPA has a mandate to perform health based risk assessments that are likely to force additional restrictions on chromate use. Alternatives to chromium need to be aggressively investigated at the level of basic understanding required to confidently make choices for substitution.

The Task Force urges increased support of basic science (6.1) and advanced technology (6.2) efforts to assure understanding of corrosion phenomenology. The Task Force recommends identification and funding of critical R&D gaps as well as non-traditional corrosion areas with unfulfilled needs such as better understanding of corrosion phenomena involving corrosion mode transitions (e.g., pits-to-cracks, paint failure-to-underpaint corrosion to exfoliation, etc.), understanding of the stochastic versus deterministic nature of corrosion, and improved utilization of distributed sensors. Accelerated laboratory and proving ground type testing should also be accompanied by increased funding for basic mechanistic understandings of accelerated testing results; for example, determination of what controls acceleration factors and establishment of the "portability of accelerated tests" from one corroding system to the next.

Other basic areas that should be addressed include development of an improved material science/corrosion prevention “tool set” to enable rapid material/coating design. These should include (a) computational design of next generation materials, treatments and coatings, (b) high throughput synthesis and testing of new materials, coatings, treatments, etc. using combinatorial methods, and (c) multi-scale modeling of corrosion processes to replace trial and error approaches to design of new prevention strategies. Effort should also be invested in developing smart, multi-functional materials to enable sensing and self-healing.

NEED FOR INTEGRATED/PREDICTIVE ENGINEERING TOOLS FOR SYSTEM DESIGN AND MANAGEMENT

The overall challenge is to understand and predict system performance including corrosion mode transitions, statistical distributions in damage evolution, complex materials and environmental issues as well as linking damage evolution with the full spectrum of chemical, mechanical, and electrochemical driving forces for a variety of corroding subsystems. These include paint failure and loss of coating function, etc., and should not be limited to effects of corrosion on fatigue of structural materials (focus of a current DARPA program). Currently, reliable probabilistic and deterministic assessment methods are not available to enable condition based maintenance, prognostics, or life prediction of a variety of subsystems common to DoD assets. The Task Force recommends the development of macroscopic models for evolution of corrosion damage for a variety of cases. Ideally these models will link subsystem level responses that affect structural integrity or functionality, to materials level (i.e., microstructure) conditions, defects, chemistries, and structures. A well-coordinated S&T program should enable the development of integrated corrosion model(s) for predicting failure and mission readiness. In conjunction with the development of predictive model, the DSB Task Force urges continued and expanded support of basic S&T into the forms and phenomenology of corrosion modes. This is needed in order to provide high quality inputs for such predictive capabilities; emerging

models will only be as good as the rate laws, damage evolution scenarios, as well as the initiation and arrest criteria that they contain.

A comprehensive performance-assessment capability will include deterministic sub-models for time evolution of surface environments, and for predicting the initiation, propagation, and cessation (stifling, arrest) of each mode of corrosion failure (pits, crevices, cracks). For coatings, traditional metal corrosion protection systems are made up of individual processes with little S&T understanding of the whole system or its parts. Each step in the protection scheme has performance requirements, usually expressed in terms of some metric like a salt spray test with less focus on total system performance assessment or prediction. Formal and controlled model abstraction is needed to facilitate probabilistic risk assessment. Knowledge about the underlying causes and degree of uncertainty and variability of all parameters and inputs is also needed.

There is a strong need to develop sensor technology for early warning, for data collection to improve understanding of corrosion processes as they occur in the field, and for performance confirmation. Included among the needs are methods for widespread detection and quantitative characterization of corrosion such as that leading to fatigue and/or environmental fracture. These methods should be based on a combination of external sensors (ideally non-contact and able to operate at a stand-off) and distributed sensors integral to the material or structure. The development should lead to sensors whose output can be quantitatively related to the extent of damage and for which physics-based models are available for accurately predicting performance during design and assessing performance during operational life. "Smart coating" technology that also serves as an indicator of underlying corrosion could provide an inexpensive means of monitoring corrosion and model feedback. Relevant issues include prognosis, probabilistic risk assessment, multi-scale modeling and simulation, and data management and fusion. The Task Force also recommends development of mathematical tools to enable simulation

and prediction of corrosion processes that accept feedback and midcourse correction of predicted damage states from such sensors.

In a practical sense, the use of such models will likely always be limited to analysis of equipment components or sub systems selected as suspect, rather than an entire weapon system. While the accuracy of such models is seldom perfect, it is realistic to believe that acceptable accuracy can be achieved, perhaps within the next decade, if corrosion data collection systems and feedback loops are put in place today. Predictions based on such models would be credible. This credibility, taken to the budget table, would support hardware design strategies and O&S resource levels sufficient to ensure that corrosion performance targets can be met.

The data collection systems and data feedback loops needed to populate a corrosion simulation model ten years from now are the same as discussed in Chapter 3. While it may take some time to digitally replicate today's human experts in an "expert system," near-term cost and readiness improvements can be expected to derive from improved corrosion data management.

NEED FOR UNDERSTANDING OF EVOLVING MATERIALS AND ENVIRONMENTAL ISSUES

The S&T role in hazardous material alternatives is crucial to preventing an escalation of corrosion control costs as chromates and heavy metals are phased out due to worker safety and environmental pressures. Many proposed protection strategies are unproven over the long run and lack fundamental and, in some cases, a practical basis for acceptance. Unlike chromates, many current generation non-chromate inhibitors have not shown consistent performance among the various aluminum alloys used on a single weapon system. Performance measures often lack scientific basis (e.g., salt spray tests) or correlation with long-term real world performance. Traditional evaluations of corrosion control systems are not sufficient for rapid discovery, verification, and acceptance of replacement materials.

Hence, trial and error approaches prevail. Traditional lab testing and lessons learned from field evaluations provide value but require years to assess performance. Thorough understanding of corrosion protection mechanisms for non-toxic corrosion inhibitors is needed if useful evaluations of alternative materials are to be completed quickly. Mathematical tools that could help engineers assess the long term protection properties at a defect site, including chemical and electrochemical throwing power, should be advanced. Coordination among DoD, industry and academia is needed to avoid fragmented solutions. In many cases, commonality of platforms across DoD suggest multi-Service solutions should be cost effective, such as for chromate replacement on high strength aluminum alloys.

The continued use of legacy equipment beyond original design boundaries (lifetime, operating environment, etc.) implies the need for fundamental corrosion studies that address corrosion at various advanced stages of development and at conditions equivalent to long term exposure. In other words, testing of corrosion initiation and propagation are insufficient, since extended use of legacy materials in conditions of advanced damage evolution requires that issues such as corrosion stifling/re-initiation and corrosion site coalescence and interaction be confronted as well. These issues may escape attention in new systems when corrosion damage is typically less extensive. Also, emerging/evolving new materials, such as ceramics and metallic glass, while providing performance enhancing benefits will have their own corrosion problems that are not yet known or understood.

The Task Force recommends a significantly increased S&T effort to develop the scientific basis and materials/corrosion toolsets needed for:

- Selection and reliability of toxic materials replacement
- Green technologies needed for corrosion control for environmental compliance

- Incorporation and use of emerging materials with corrosion problems that may not be understood
- Extension of legacy equipment beyond original design life

STATE OF S&T

Corrosion S&T is currently a small fraction of 1% of the S&T budget and is largely a hodge-podge of scattered efforts funded to a large degree by either environmentally driven requirements (e.g., EPA, OSHA) or by Congressional adds. A major fraction of this could be properly categorized within budget area 6.3, if in S&T at all. As outlined in the preceding sections, there is a real need for more work that fits the basic research definitions applicable to budget areas 6.1 and 6.2.

A healthy research program exists in a few areas such as the Navy nuclear reactors program, but other S&T areas generally have no dedicated, consistent S&T program in corrosion. There are certainly exceptions and examples of visionary S&T. Examples include:

- The DARPA funded prognostics programs aimed at structural material corrosion/fatigue
- The Air Force funded KC-135 corrosion control program aimed at understanding the effects of corrosion on structural integrity and factoring such corrosion into aircraft structural integrity programs (ASIP)
- The two Air Force Office of Scientific Research-led MultiService University Research Initiative (MURIs) (Ohio State – Understanding of Chromate Inhibitors and University of Virginia directed MURI on system understanding of novel multi-functional coatings)

Similarly, commercial (Delta Airlines) and DoE (Sandia National Laboratories) risk assessment methodologies provided examples of

visionary approaches to achieve combinations of high equipment reliability, low life-cycle cost, and high operational availability for their respective assets.

Individual research projects of intensely scientific nature, funded by individual agencies, also have been of great value. One example was an ONR program to understand environmental fracture in high strength alloys and the fundamental strategies and attributes of both the alloys themselves and cadmium replacement coatings that could mitigate fracture susceptibility if carefully designed. By studying the fundamental attributes of high strength alloys and coatings that govern fracture instead of trial and error empirical approaches to solving cracking susceptibility, generic long lasting information will be developed whereby a variety of future coatings could be tailored to fit the desired attributes and characteristic properties identified to help control environmental embrittlement of a variety of structural alloys. This generic basic science would apply to many coatings and many high strength alloys and thus long lasting generic benefit will be created by this relatively small S&T investment.

However, there were also many examples given of mature technology development or RDT&E work that could yield only empirical findings. Some of this was termed S&T and consumed scarce S&T resources.

S&T FINDINGS

The following are the overall findings of the Task Force in regard to the current DoD S&T program in corrosion control:

- S&T investment is fragmented and inconsistently funded for achievement of long term gains
- Current funding levels are too low by about a factor of three

- There is little or no redundancy in corrosion S&T portfolios observed given the diversity of issues and platforms in the various Services, and no reason to suspect redundancy given the small size of the total funding. S&T resources are not being squandered by research overlap
- The current S&T emphasis is on technology applications with inadequate investment in basic scientific understanding
- Several areas of corrosion technology research have unfulfilled funding needs that, if resourced, could produce high impact
- There is adequate communication across the corrosion S&T community, among the Services and across warfare communities, providing ample means for applying technology developed in one area to another

OVERALL RECOMMENDATIONS

In general, there appears to be an under investment in corrosion-control science and technology that is directed towards the existing challenges as well as directed at furthering the understanding of basic mechanisms. This is one of the barriers to achieving a reduction in corrosion control costs. DoD should strive to establish steady and consistent funding levels for corrosion control research, since a consistent approach will save money in the long run.

	Recommendation	Implementation
5	Refocus and reinvigorate corrosion S&T portfolio; triple the effective funding in this area (+$20M)	Particular emphasis on: • Development of a materials-corrosion toolset that emphasizes science-based modeling & simulation • Fundamental mechanistic understandings of corrosion phenomena as well as accelerated testing • Substitutes for effective corrosion prevention materials that are being withdrawn due to environmental and safety considerations • Newly developed materials • Non-destructive corrosion sensing/measurement in the field as feedback to prognostic and condition-based maintenance tools

Recommendation #5 is to refocus and reinvigorate the corrosion S&T portfolio and, in order to affect this, tripling the effective funding in this area. Although the level of S&T funding directly related to corrosion effects is uncertain, it is estimated that an additional $20 million per year would be required.

The increased S&T funding should have particular emphasis on:

- Fundamental mechanistic understandings of corrosion phenomena as well as accelerated testing
- Substitutes for effective corrosion prevention materials which are being withdrawn due to environmental and safety considerations
- Development of a materials-corrosion toolset(s) that emphasize science-based modeling & simulation

- Newly developed structural and non-structural materials
- Corrosion sensing/measurement in the field as feedback to prognostic and condition based maintenance tools

CHAPTER 7. RECOMMENDATIONS AND CONCLUSIONS

The preceding chapters have discussed the findings and needs and have offered five major recommendations that are summarized below. In these chapters, each of these recommendations is accompanied by a series of near-term implementation steps that are recommended to effect the changes called for in the major recommendation.

Summary of Recommendations

1. **Promulgate and enforce policy emphasizing LCC over acquisition costs in procurement and provide the incentives and training to assure that corrosion costs are fully considered in design, manufacturing, and maintenance.**
2. **Mandate and implement comprehensive and accurate corrosion data reporting systems across DoD using standard metrics & definitions**
3. **Fund contract for comprehensive assessment of all DoD weapon system equipment with ~30 five-person teams of corrosion experts and use the results to develop and implement a corrosion strategy**
4. **Establish Corrosion Executive for each Service with responsibility for oversight and reporting and full authority over corrosion-specific funding and a strong voice in corrosion-related funding**
5. **Refocus and reinvigorate corrosion S&T portfolio; triple the effective funding in this area (+$20M)**

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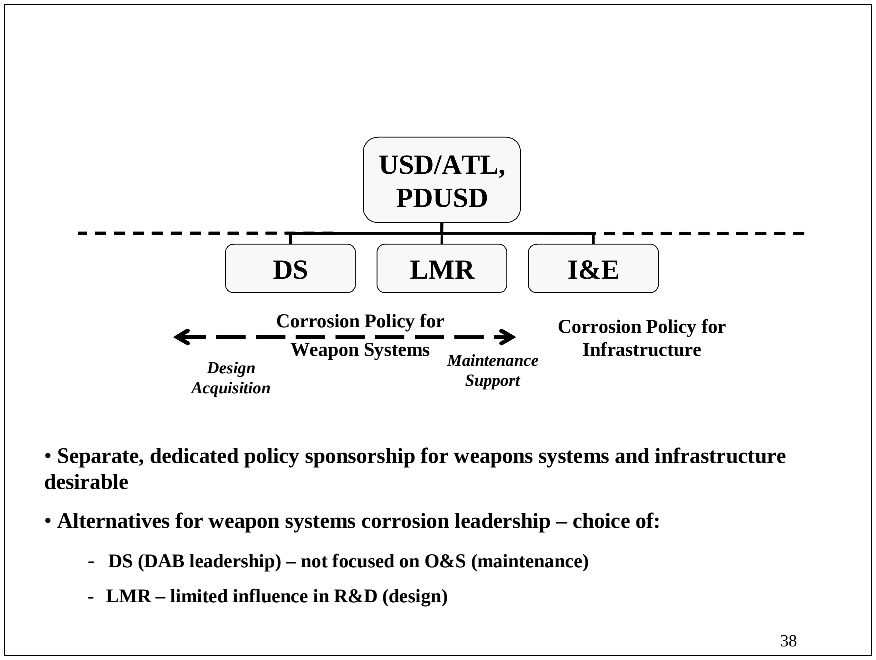
The estimated cost for implementing all of these recommendations is approximately $50 million in the first year, assumed to be FY05. Once the foundations are laid in this first year, additional investment in preventive design in future years should be $100-150 million per year but this will quickly (within 1-2 years) be offset by corresponding and larger reductions in O&S.

Figure 12.



The Task Force debated alternative organizational locations for corrosion policy oversight within the Department, and concluded that separate, dedicated policy sponsorship for defense weapons systems and for defense infrastructure was desirable. Within ATL, the Installations and Engineering Office is the only logical location for issues dealing with the cost and safety implications of infrastructure corrosion. See Figure 12.

The weapons systems responsibility is more complex because there are two major and equally important areas, the near term represented by weapon system maintenance and repair, and the longer term represented by weapon system design and manufacture. Assigning the responsibility to DS is appropriate for the longer term aspects of corrosion cost reduction since that office leads the Defense Acquisition Board (DAB), but Defense Systems (DS) has little focus on current readiness and O&S costs. On the other hand, Logistics, Materiel, and Readiness (LMR) is completely focused on current

readiness and cost, but has little influence in weapon system R&D or design.

The Task Force reached no conclusion on the details of policy oversight. One option is to separate the responsibility into the logical three components that line up with the ATL organization and maintain the Principal Deputy Under Secretary of Defense (PDUSD) as OSD focal point. This could be satisfactory if that official can afford the time necessary to give the subject adequate attention. However, it is important to maintain a centralized focal point for corrosion at the staff level, reporting to the DoD Corrosion Executive. This group, as it does now, is responsible for pulling together the diverse efforts and assuring that the DoD Corrosion Executive is kept fully informed on issues and problems in the area.

APPENDIX I. TERMS OF REFERENCE

THE UNDER SECRETARY OF DEFENSE

3010 DEFENSE PENTAGON
WASHINGTON, DC 20301-3010

NOV 4 2003

ACQUISITION,
TECHNOLOGY
AND LOGISTICS

MEMORANDUM FOR CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Terms of Reference—Defense Science Board Task Force on Corrosion Control

You are requested to establish a Defense Science Board (DSB) Task Force on Corrosion Control.

As fiscal and physical resources continue to be reduced while mission tasking remains constant, combat systems must be maintained at the highest possible readiness state. A significant threat to combat readiness is the susceptibility of equipment to corrosion. Corrosion is a threat, in some measure, to every combat and support system. It is a function of application, construction and environment. Corrosion control can be addressed through out a combat system's lifecycle: design, construction, operation and maintenance.

The Task Force should assess current on going corrosion control efforts across the Department of Defense with particular attention to the following:

- Duplication of research efforts
- Application of current and future technology which currently exists in one area to other areas (i.e. submarine applications which might translate to aircraft applications)
- The current state of operator and maintenance personnel training with regards to corrosion control and prevention.
- The current state of maintenance processes with regards to corrosion control and prevention.
- The incorporation of corrosion control and maintainability in current acquisition programs (during the design and manufacturing stages)
- Identify unique environments important to National Security but with little commercial application (e.g. nuclear weapons).

The Task Force should conduct an analysis of the findings generated and determine which areas, if adequate resources were applied, would provide the most significant advances in combat readiness. In addition, the Task Force should assess best commercial practices and determine their applicability to DOD needs.

The study will be sponsored by me as the Acting Under Secretary of Defense (Acquisition, Technology and Logistics) and Deputy Under Secretary of Defense (Logistics and Materiel Readiness). Mr. Larry Lynn will serve as the Task Force Chairman. Colonel Sarah Smith, USAF will serve as the Executive Secretary. Lieutenant Colonel Roger Basl, USAF will serve as the Defense Science Board Secretariat representative.

The Task Force will operate in accordance with the provisions of P.L. 92-463, the "Federal Advisory Committee Act," and DOD Directive 5105.4, the "DoD Federal Advisory Committee Management Program," It is not anticipated that this Task Force will need to go into any "particular matters" within the meaning of Section 208 of Title 18, U.S. Code, nor will it cause any member to be placed in the position of acting as a procurement official.

FOR

Michael W. Wynne
Acting

APPENDIX II. TASK FORCE MEMBERSHIP

CO-CHAIRMEN

RADM Steve Heilman, USN (Ret.)	LMI
Mr. Larry Lynn	Private Consultant

TASK FORCE MEMBERS

Dr. Robert Baboian	Private Consultant
Mr. Aubrey Carter	Delta
Dr. Michael Cieslak	Sandia National Laboratories
Dr. David Diehl	PPG Industries
Dr. Joseph Farmer	Lawrence Livermore National Lab
Dr. Robert Green	Johns Hopkins University
Dr. Arthur Heuer	Case Western Reserve University
Mr. Brian Manty	MB-TSI
CAPT William Needham, USN(Ret.)	Naval Surface Warfare Center
Dr. Richard Pinckert	Boeing
Dr. Rick Ricker	NIST
Dr. John Scully	University of Virginia
Dr. Bruce Thompson	Iowa State University
Dr. Neil Thompson	CC Technologies, NACE

EXECUTIVE SECRETARY

Col Sarah Smith, USAF

DSB REPRESENTATIVE

LtCol David Robertson, USAF

GOVERNMENT ADVISORS

Maj Dan Bullock, USAF	AFRL
Mr. Roger Griswold	AFRL
Maj Claxton Johnson, USMC	

CAPT Philip Johnson, USN
CW5 Theodore Walker, USA

STAFF

Ms. Grace Johnson	Strategic Analysis, Inc.
Ms. Stacie Smith	Strategic Analysis, Inc.

APPENDIX III. BRIEFINGS

December 9-10, 2003: Arlington, VA	
BRIEFER	***TOPIC***
Mr. Allen Westheimer, GAO	Review of GAO Report: Opportunities to Reduce Corrosion Costs and Increase Readiness
Mr. Dan Dunmire, OSD Col Larry Lee, OSD Dr. Lew Sloter, OSD	Review of Report to Congress: Long-Term Strategy to Reduce Corrosion and The Effects of Corrosion on the Military Equipment and Infrastructure of the Department of Defense
Mr. Bob Stith, USMC	Marine Corps Corrosion Program Overview
Mr. Hilton Mills	Army Corrosion Program Overview
Mr. Beau Brinkerhoff Mr. Dale Moore Dr. Robert Pohanka	Navy Corrosion Program Overview
Maj Dan Bullock, AF Corrosion & PVtn Ofc, WR-ALC	AF Corrosion Program Overview
Mr. Dan Dunmire, OSD Col Larry Lee, OSD Dr. Lew Sloter, OSD	DoD Corrosion Policy and Oversight Office Update, DoD Corrosion Prevention Control IPT, The Science and Technology of Corrosion Prevention and Control
February 2-3, 2004: Arlington, VA	
ADM Don Pilling, USN (Ret)	KC-135 Corrosion Discussion
Mr. Dave Curtis	Naval Reactors (**Classified)**
CDR Jim Syring	DDX
Mr. Chris Bolkcom Mr. Bill Mullis	Congressional Research Service Tanker FMTV Program and Corrosion Control

Col Sarah Smith, USAF	DoD Corrosion Control & Prevention Policies for Weapon Systems
CAPT David Lewis	DDG 51 Presentation
Col Sarah Smith, USAF	Military Training Programs for Corrosion Control
Col Sarah Smith, USAF	Royal Australian AF Corrosion Program on F-111 and F-18
Mr. Ken Herd, GE Global Technology Leader, Inspection and Manufacturing Technologies	General Electric Initiatives in Corrosion Control
February 25-26, 2004: Arlington, VA	
Dr. Leo Christodoulou, DARPA	DARPA Programs
Mr. Greg Saunders Mr. Steve Lowell, Defense Standardization Program Office, DLA	Standards and Specifications
Dr. Dave Diehl	Near Term Effects/Solutions
Mr. Steve Finley, AFMC/LGPE	Pollution Prevention Technologies and Corrosion Control
Dr. John Beatty, ARL	Army S&T
March 15-16, 2004: Arlington, VA	
Mr. Roger Griswold Dr. John Scully	Visit to KC-135 Depot Line at Tinker AFB
Dr. Neil Thompson	Corrosion Costs
Dr. Joe Farmer	Corrosion-Resistant Materials for the Safe Long-Term Storage of Spent Nuclear Fuel
Lt Col Paul Trulove	AF Office of Scientific Research Corrosion Program
Dr. Joe Gallagher	Aircraft Structural Integrity Program
Col Sarah Smith, USAF	Condition Based Maintenance Plus in DoD
Mr. David H. Rose, AMPTIAC	Reducing Corrosion Costs Through Educational Improvements and

	Improved Technology Transfer
RADM Steve Heilman, USN (Ret.)	Planning, Programming, and Budgeting System 101
April 21-22, 2004: Arlington, VA	
Dr. Lew Sloter, OSD Corrosion Office	Sensors and Detection
Maj Dan Bullock, USAF Mr. George Slenski, AFRL/MLSA	Electronic/Avionic Corrosion Prevention and Control
Mr. Jeff Braithwaite, Sandia National Laboratories	Corrosion of Electronic Devices and Predictive Modeling
Maj Timberlyn Harrington Mr. Bruce Fox, Aging Aircraft SPO	Aging Aircraft
Mr. M. Brad Beardsley Mr. Larry Seitzman	Corrosion Prevention and Control at Caterpillar
Mr. Paul Howdyshell Mr. Vince Hock, Army Corps of Engineers	Infrastructure Corrosion
Col Sarah Smith, USAF	Mr. Wynne's Video on the Corrosion Prevention and Control Program
Mr. Aubrey Carter	Delta Airlines Corrosion Control and Prevention Program
CAPT Phil Johnson, USN Maj Dan Bullock, USAF	Military Services Corrosion Control Data Call Results
Mr. Jim Moran, Alcoa Mr. Dave Williams, Alcoa Mr. Mike Skillingberg, The Aluminum Association, Inc.	Corrosion Control and the Aluminum Industry
May 10-11, 2004: Arlington, VA	
Mr. Dave Ferris	Marines Corps Corrosion Data Collection
Mr. Dan Dunmire Col Larry Lee, USAF	Update on Corrosion Prevention and Control IPT

Dr. Dave Diehl	Coatings
Mr. Larry Craigie, American Composites Manufacturers Association	Composites and Corrosion
May 24-25, 2004: Arlington, VA	
Mr. Steve Carr	Army Corrosion

APPENDIX IV. GLOSSARY OF DEFINITIONS, ACRONYMS, AND ABBREVIATIONS

ACRONYMS AND ABBREVIATIONS

AFB	Air Force Base
AFOSR	Air Force Office of Scientific Research
AMPTIAC	Advanced Materials and Processes Technology Information Analysis Center
ASIP	Aircraft structural integrity program
ATL	Acquisition, Technology, and Logistics
CAD/CAM	Computer aided design/computer aided manufacture
CCIPT	Corrosion Control Integrated Product Team
CPAT	Corrosion Prevention Advisory Team
DAB	Defense Acquisition Board
DARPA	Defense Advanced Research Agency
DAU	Defense Acquisition University
D&I	Discovery and invention
DMA	Design, manufacture, and acquisition
DoD	Department of Defense
DoE	Department of Energy
DOT	Department of Transportation
DS	Defense Systems
DSB	Defense Science Board
DT	Development testing
EPA	Environmental Protection Agency
FMTV	Family of Medium-Size Tactical Vehicles
FNC	Future Naval Capability
GAO	Government Accountability Office
IMA	Intermediate maintenance activities

LCC	Life-cycle cost
L&MR	Logistics and Materiel Readiness
MILSPEC	Military specification
MURI	MultiService University Research Initiative
NAVSEA	Naval Sea Systems Command
O&S	Operation and support
OSHA	Occupation Safety and Health Administration
OT	Operational testing
OTJ	On the job
PDUSD	Principle Deputy Under Secretary of Defense
PE	Program Element
PM	Program Manager
O&S	Operation and support
R&D	Research and development
ROI	Return on investment
RDT&E	Research, development, test and evaluation
SBIR	Small Business Innovative Research
SERDP	Strategic Environment Research and Development Program
S&T	Science and technology
T&E	Test and evaluation
USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
USMC	United States Marine Corps